Scientific Visualization

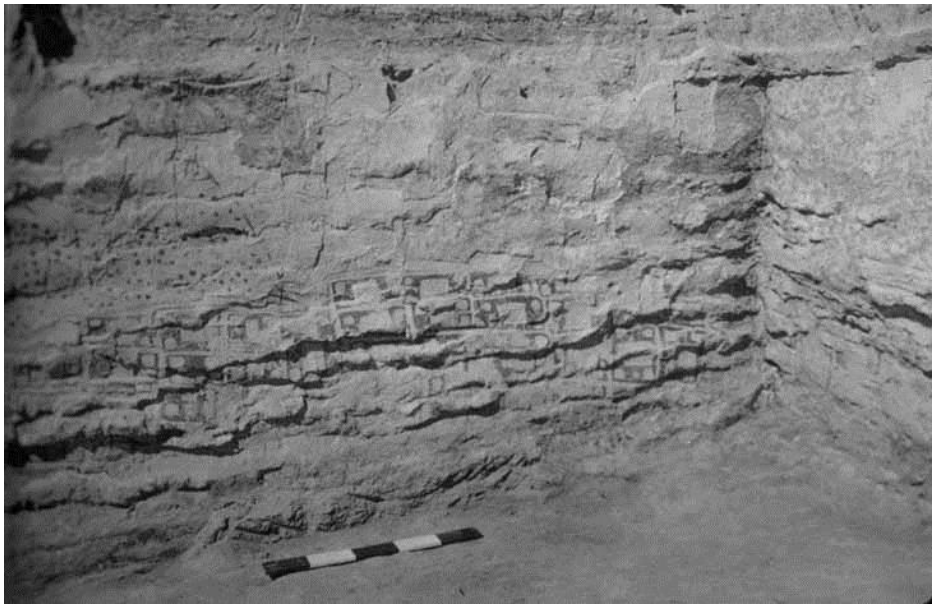
Leif Kobbelt

Visual Computing Institute | RWTH AACHEN UNIVERSITY

Overview

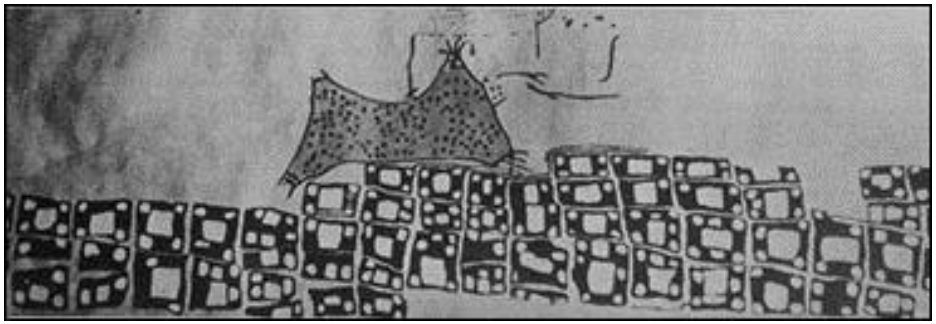
- introduction to visualization
- mapping & rendering
- data cleanup & filtering
- data structures & implementation

History



Map of Catal Hyük
6200 BC

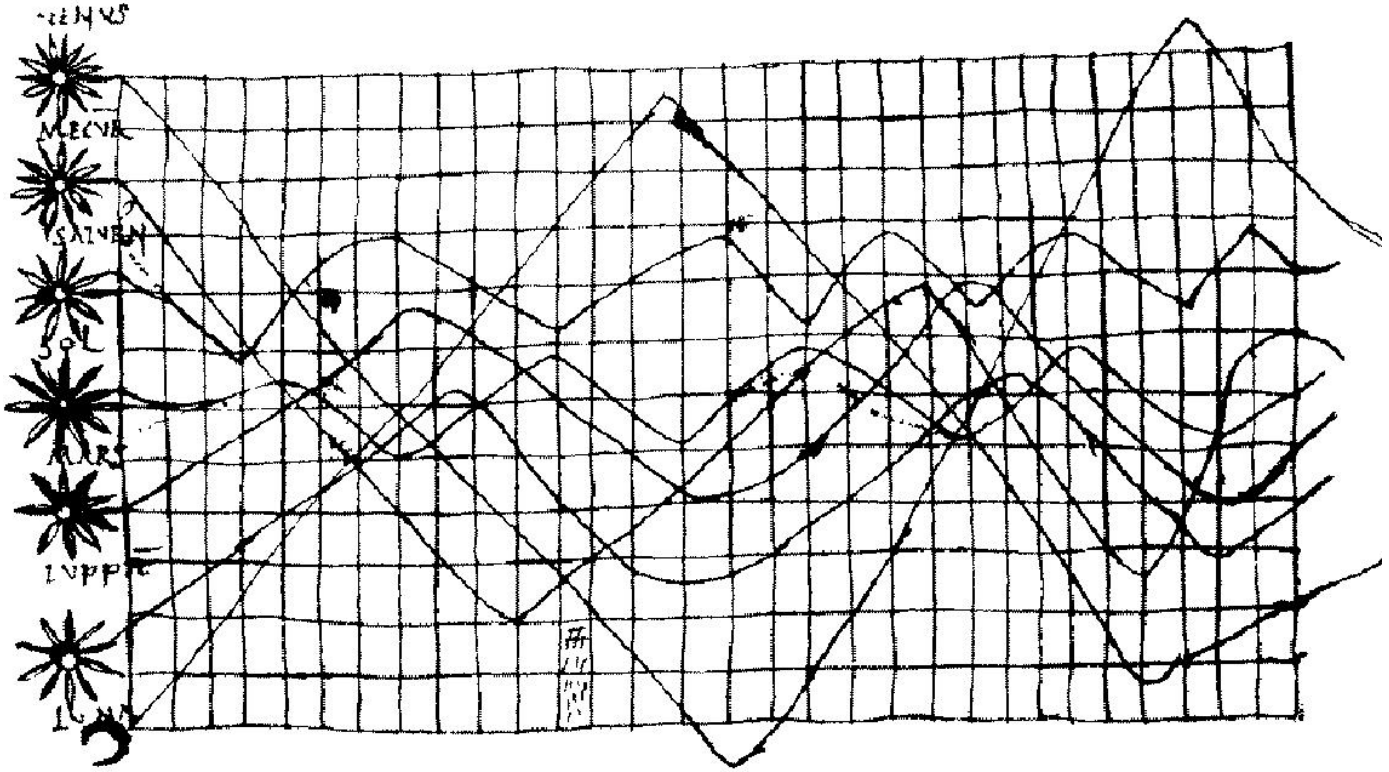
Excavation



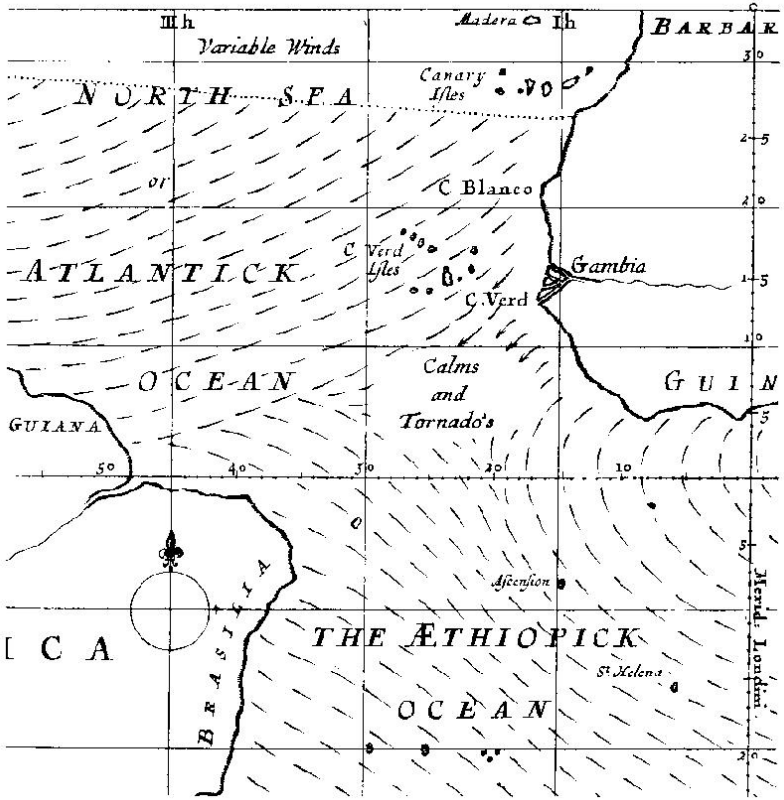
Reconstruction

History

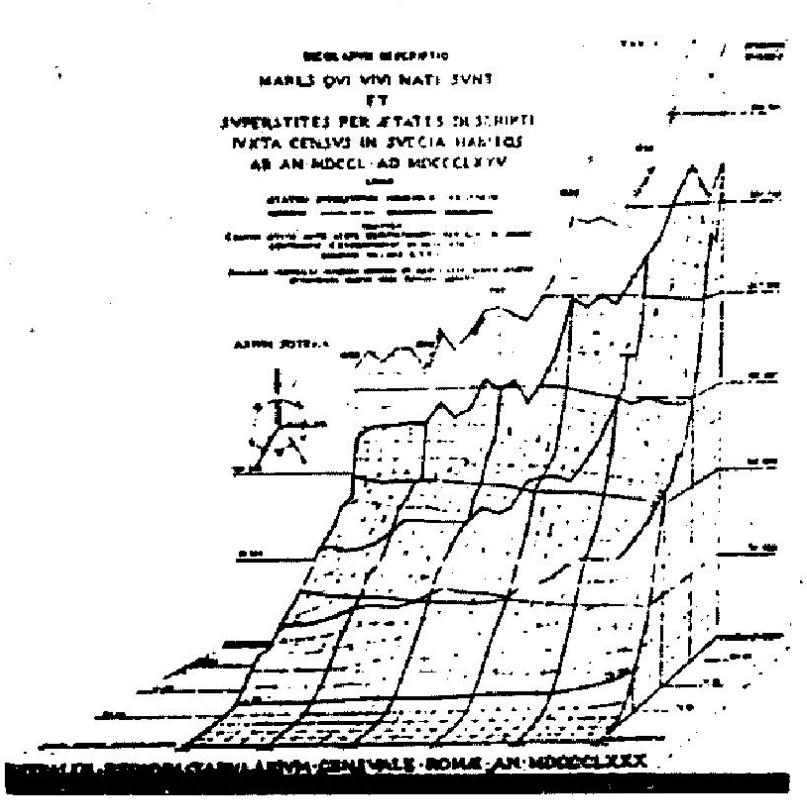
- Time series: inclination of planets (10th century)



History



Vector visualization (1686)



Height field (1879)

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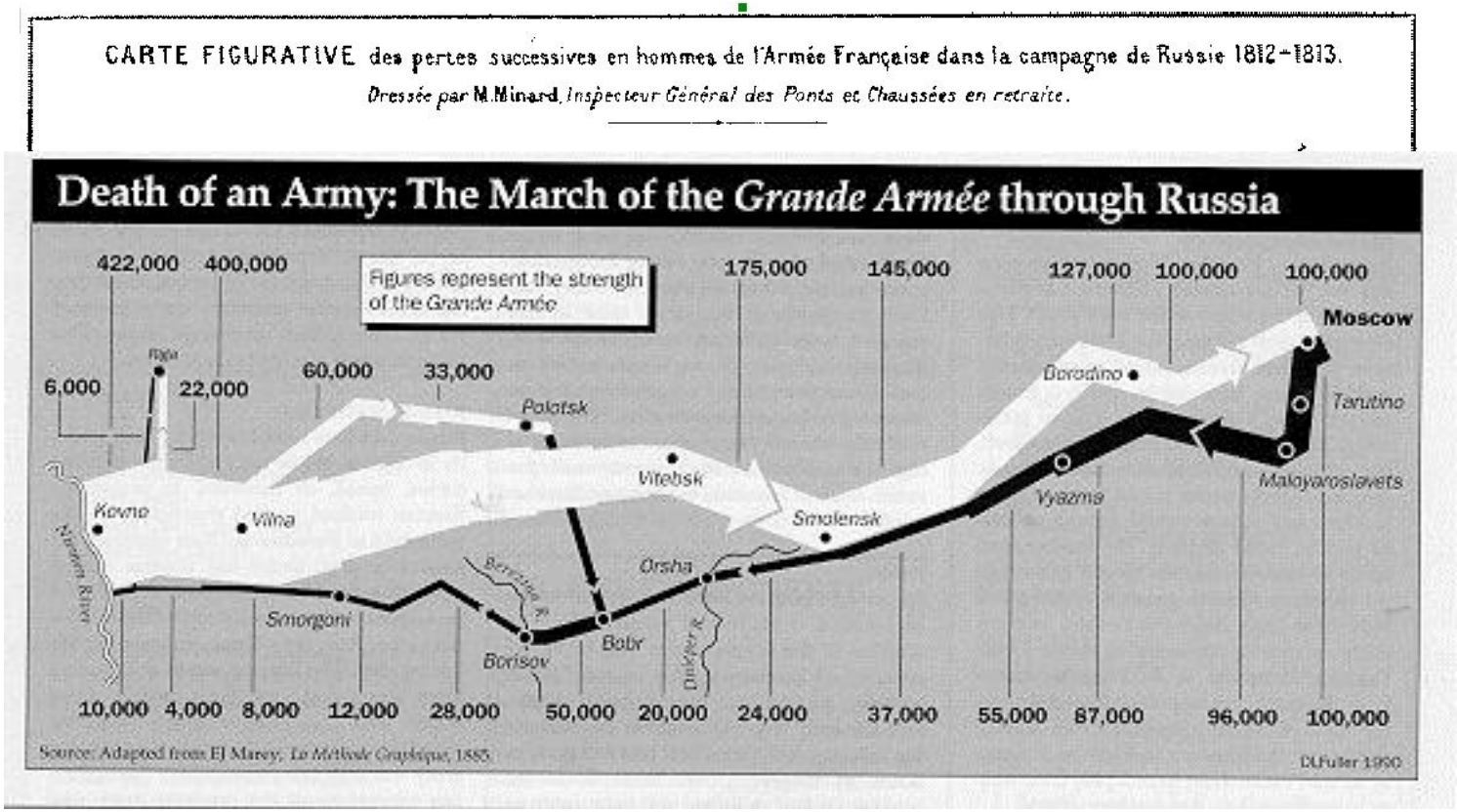
History



Napoleon‘s campaign against Russia (1812/13)
Cartography (1861)

History

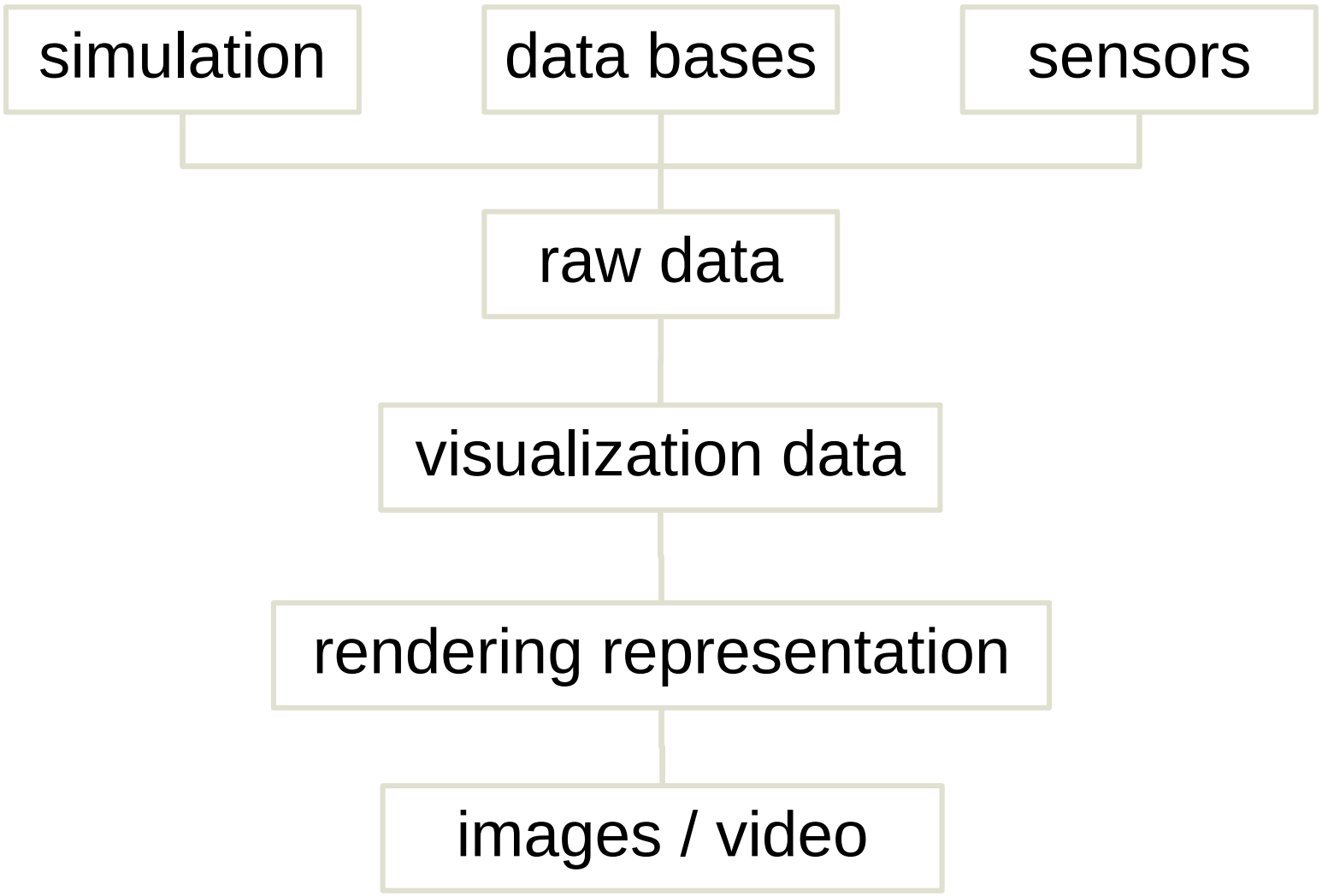
"The purpose of computing
is insight not numbers"

(Hamming 1962)

History

- direct implications
  - the data flood from super computer simulations can only be dealt with visually
  - needs a visualization specialist and an interdisciplinary team
  - new developments in hard/software, nets, etc are necessary
- advantages in the long term will be
  - faster insight
  - faster product–development cycles
  - stronger position in global competition

The Visualization Pipeline



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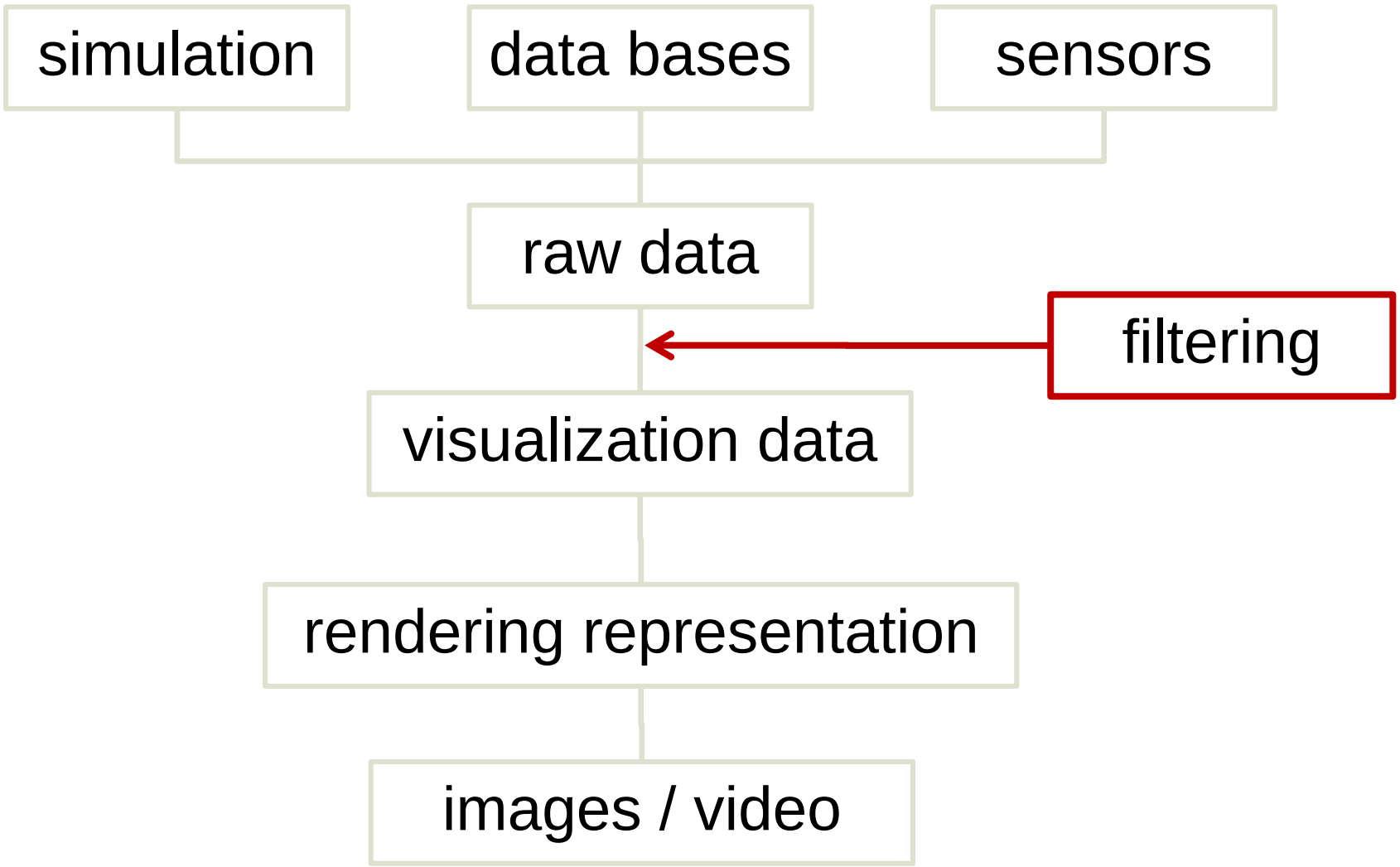

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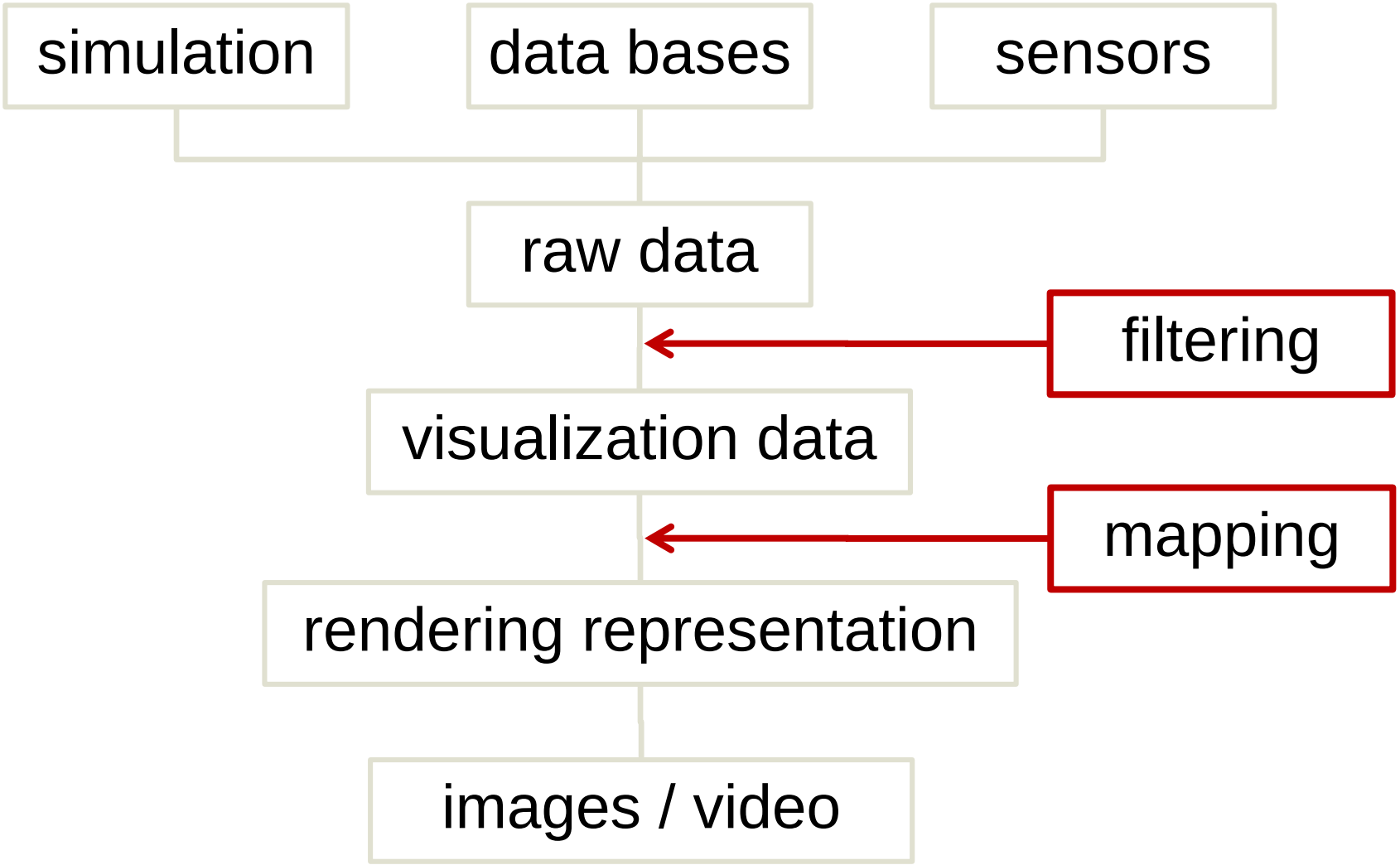

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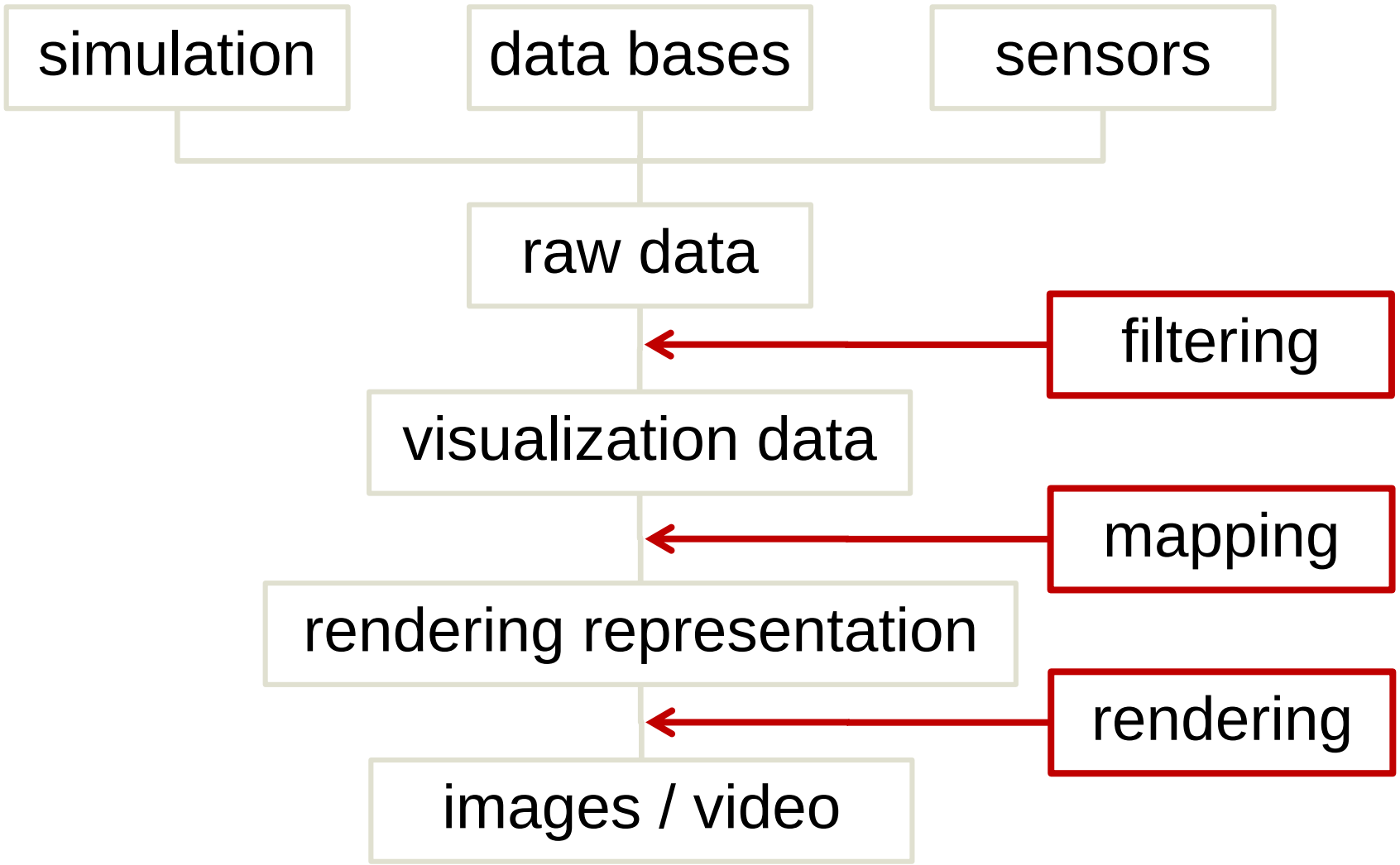

Filtering

- data format conversion
- clipping / croping
- denoising
- sub- / super- / re-sampling
- interpolation / approximation
- classification / segmentation

Mapping

- graphics primitives
  - points, lines, surfaces, volumes
  - polynomials vs. piecewise linear
  - color, texture, transparency
- iso-contours of scalar fields
- height fields
- vectors, glyphs, ...

Rendering

- geometric scenes
  - surfaces, volumes, images
- intuition
  - perspective, visibility
- realism
  - shadows, lighting, reflections

Reliability

- errors in ...
  - data acquisition
  - filtering
  - mapping / interpolation
  - rendering

Reliability

- errors in ...
  - data acquisition
    - sampling density → alias
    - quantization
  - filtering
  - mapping / interpolation
  - rendering

Reliability

- errors in ...
  - data acquisition
  - filtering
    - noise to signal ratio
    - features
  - mapping / interpolation
  - rendering

Reliability

- errors in ...
  - data acquisition
  - filtering
  - mapping / interpolation
    - approximation quality
    - intuition (plausible real world analogue)
  - rendering

Reliability

- errors in ...
  - data acquisition
  - filtering
  - mapping / interpolation
  - rendering
    - consider human perception
    - avoid distraction (too much information)
    - too much realism (pseudo information)

Types of Data

- doma
- range

$$f : R^d \mapsto R^n$$

Types of Data

- doma
  - univa
  - bivar
  - trivariate / „volumes“ (d=3)
  - quadvariate / e.g. „space-time volumes“ (d=4)
- range dimension

$$f : R^d \mapsto R^n$$

Types of Data

- doma
- range
  - sca
  - planar (n=2)
  - spatial (n=3)
  - multi-dimensional

$$f : R^d \mapsto R^n$$

} vector valued

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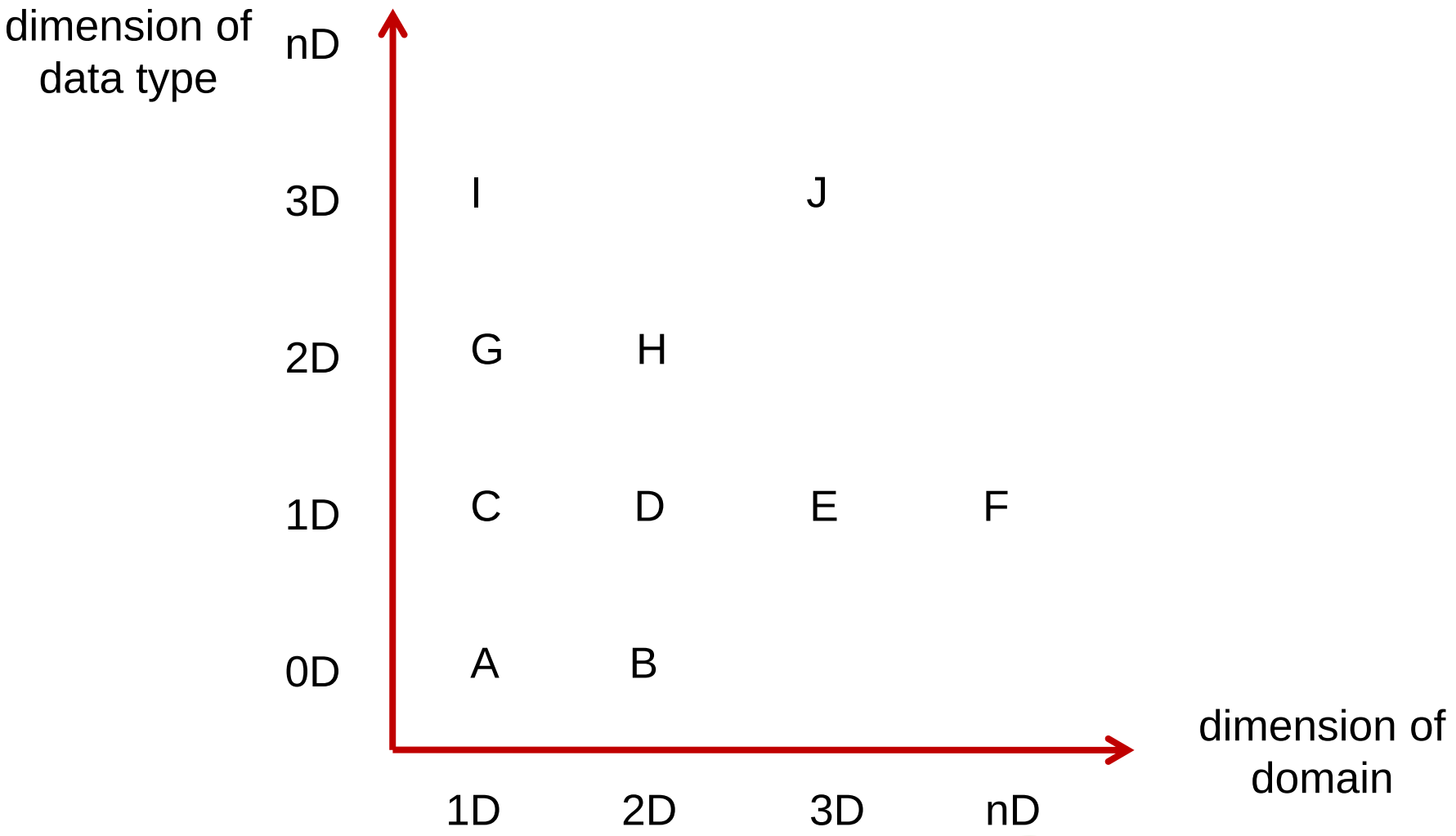
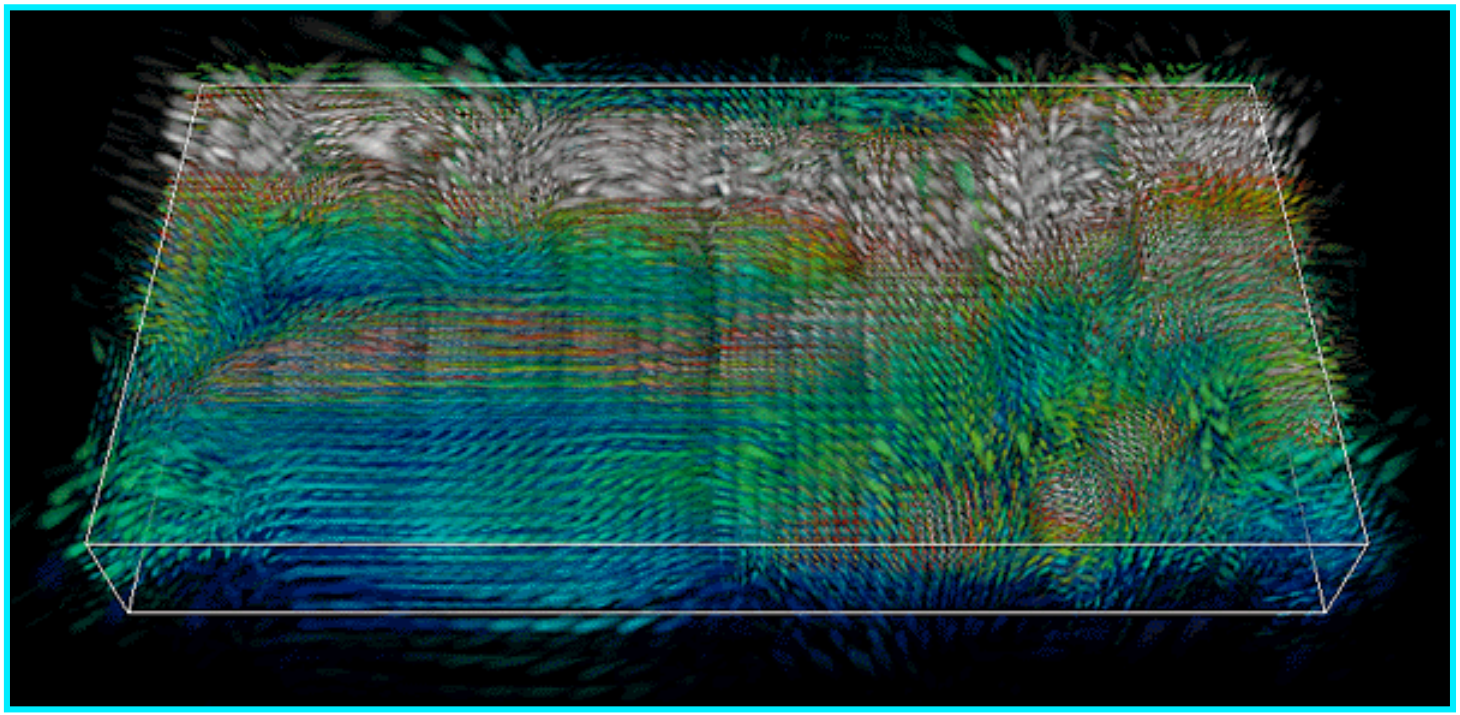
Types of Data



Applications

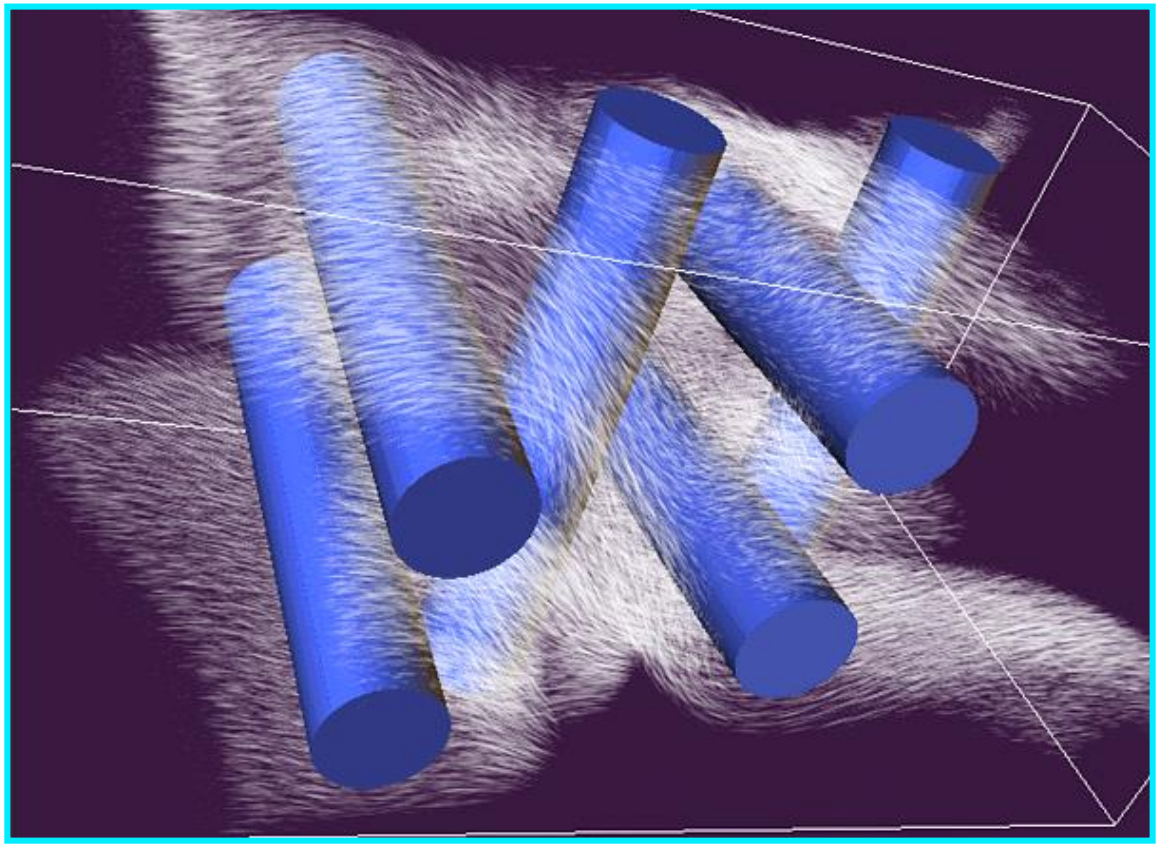
- Flow Visualization



© N. Max, LLNL

Applications

- Flow Visualization



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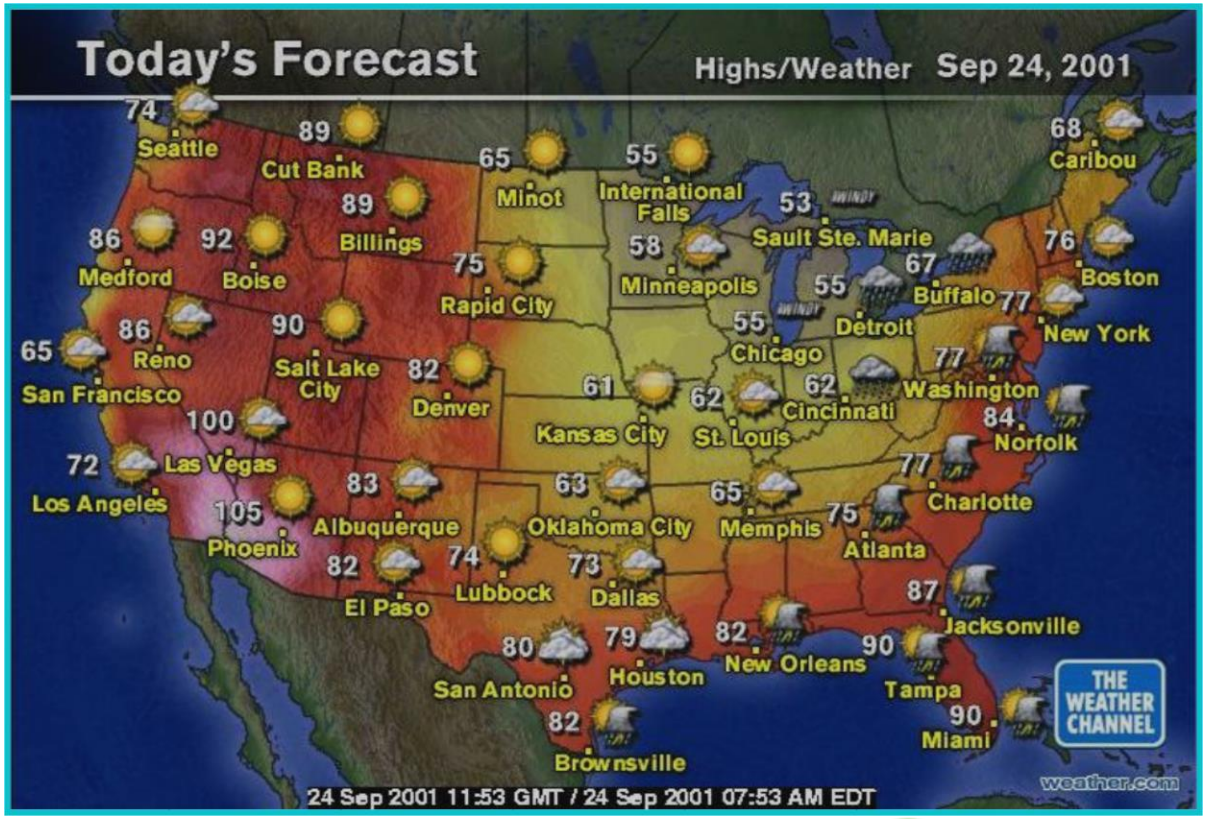
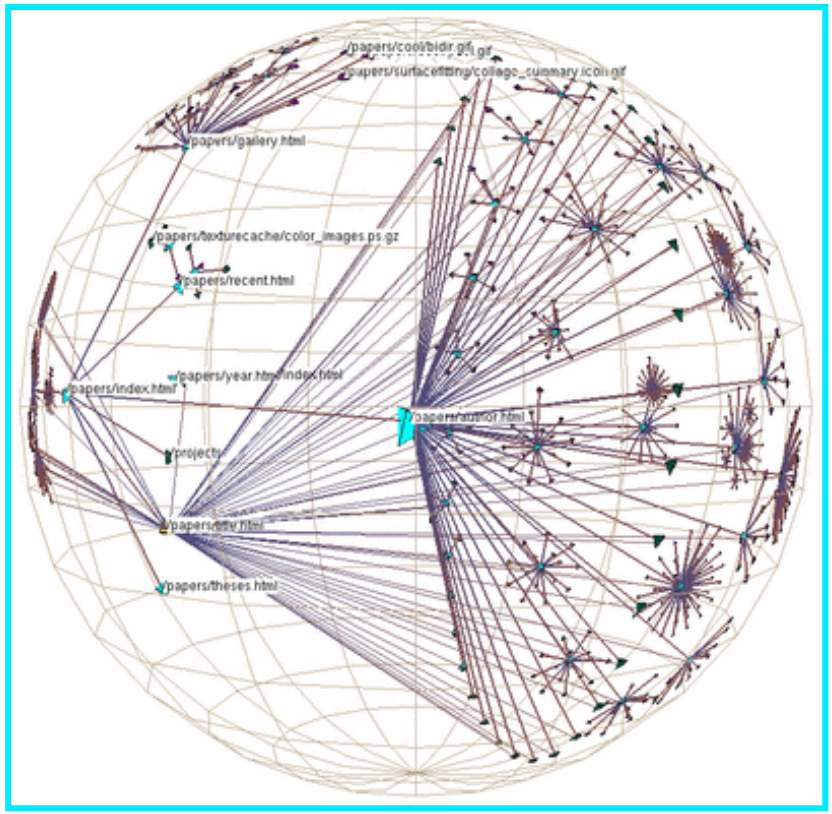
Applications

- Information Visualization



Applications

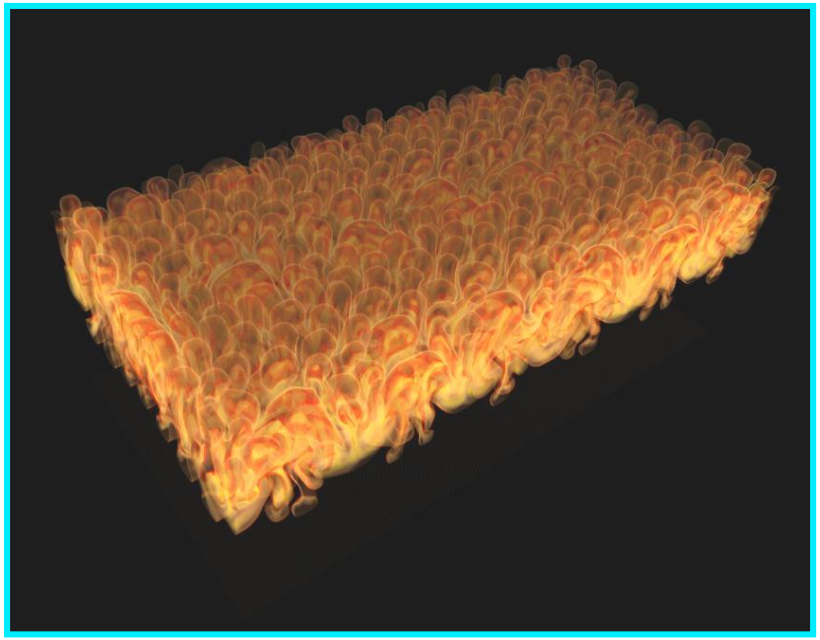
- Information Visualization

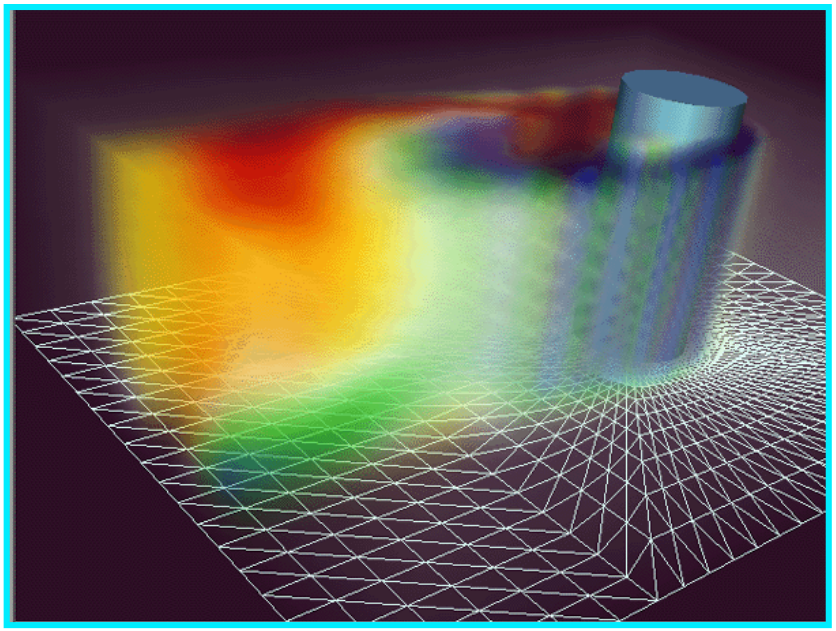


Web hyperlinks (quasi-hierarchical graphs)

Volume Visualization

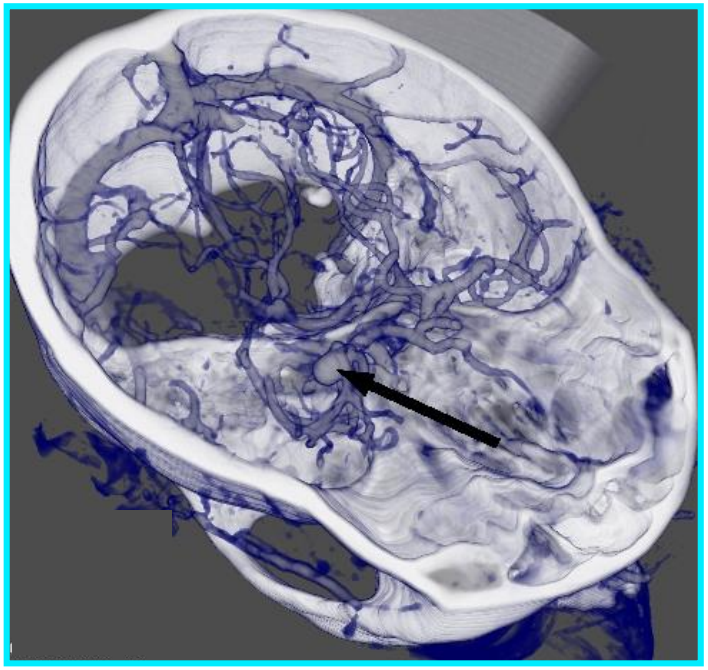
- Visualization of numerical simulation results
  - large and unstructured data sets

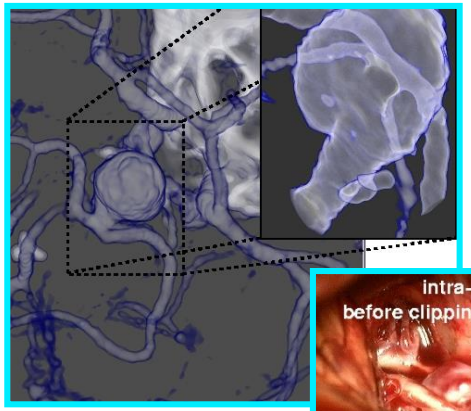


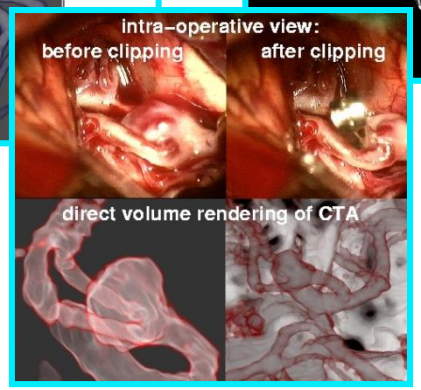


Volume Visualization

- Visualization of medical data sets
  - analysis and pre-operative planning

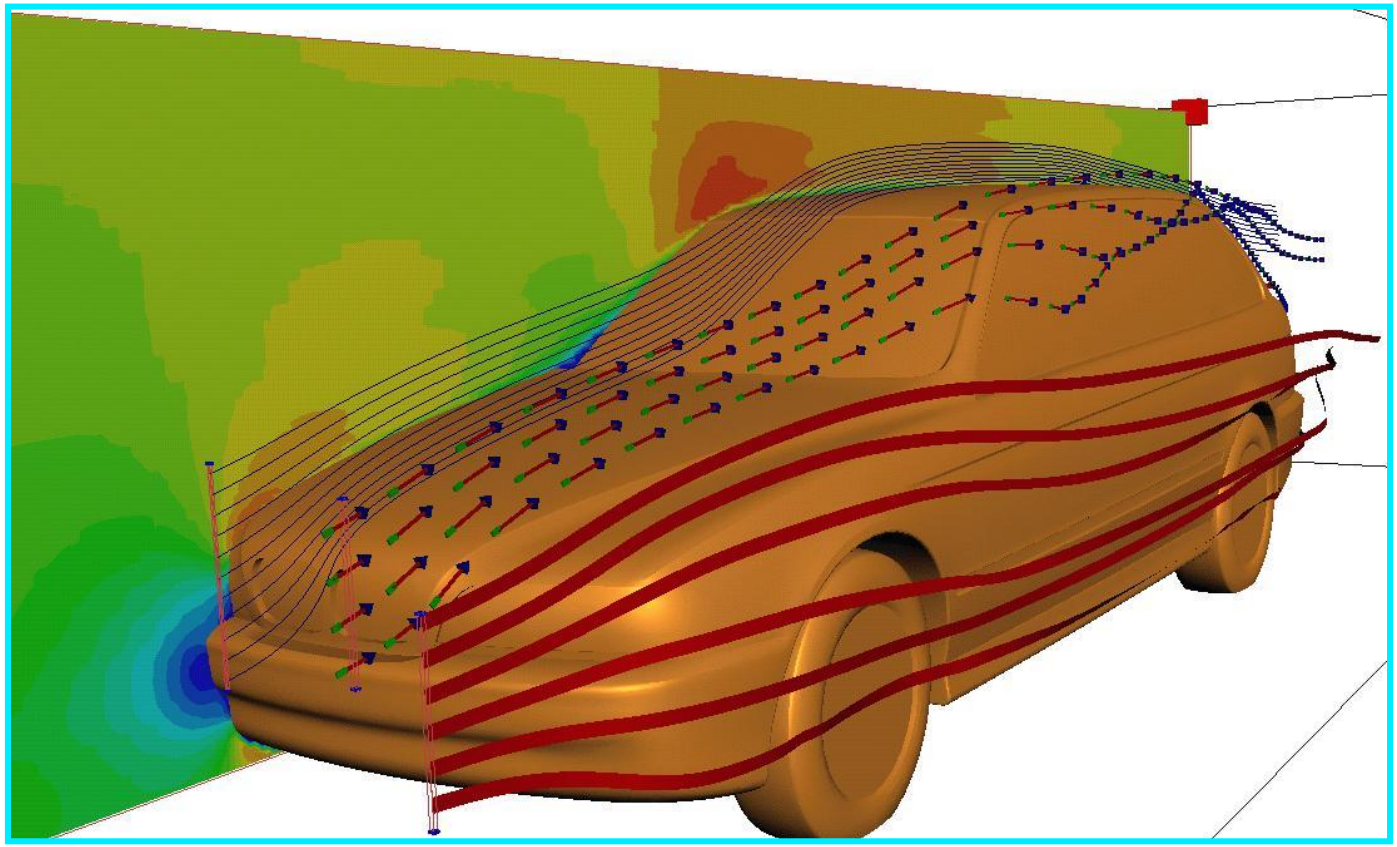






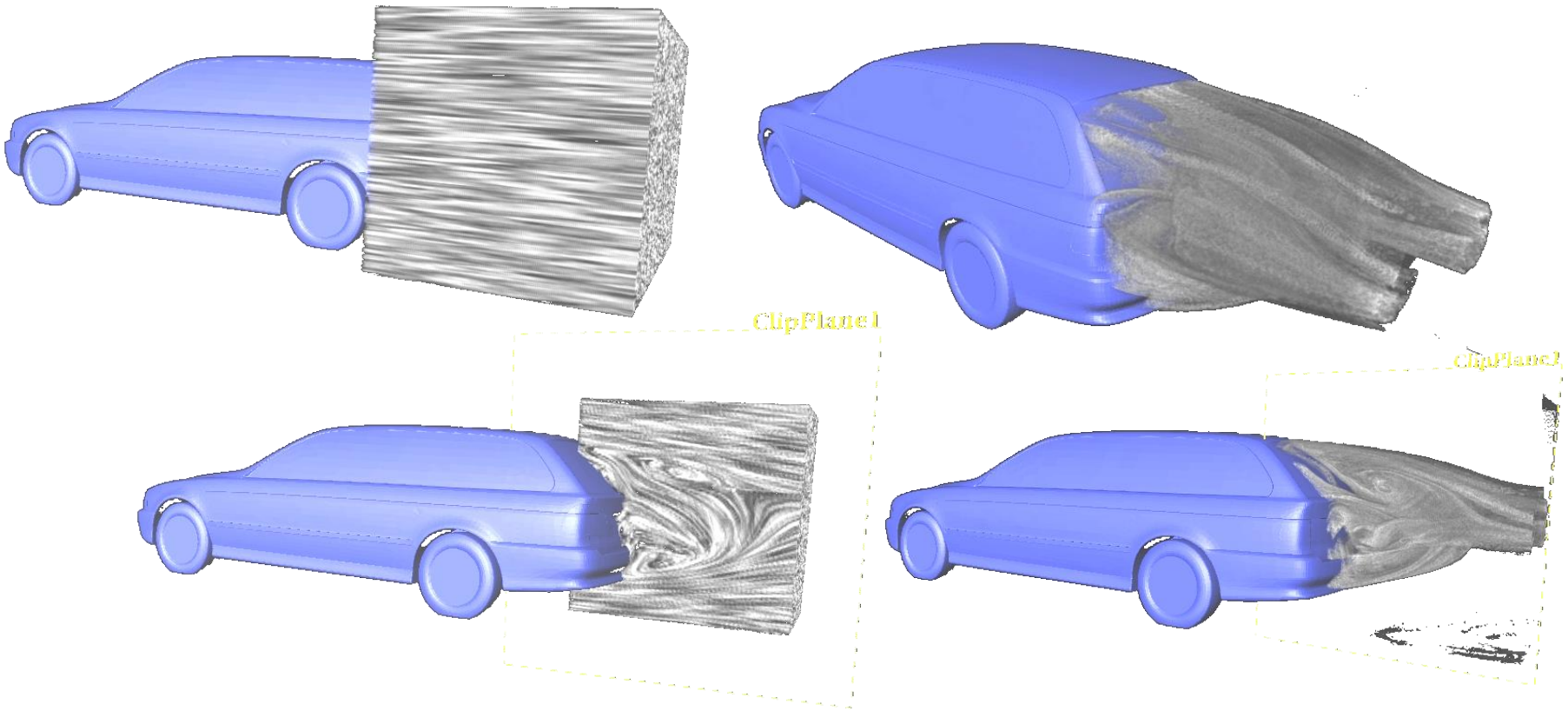
Vector Field Visualization

- Visualization of flow phenomena



Vector Field Visualization

- Feature extraction

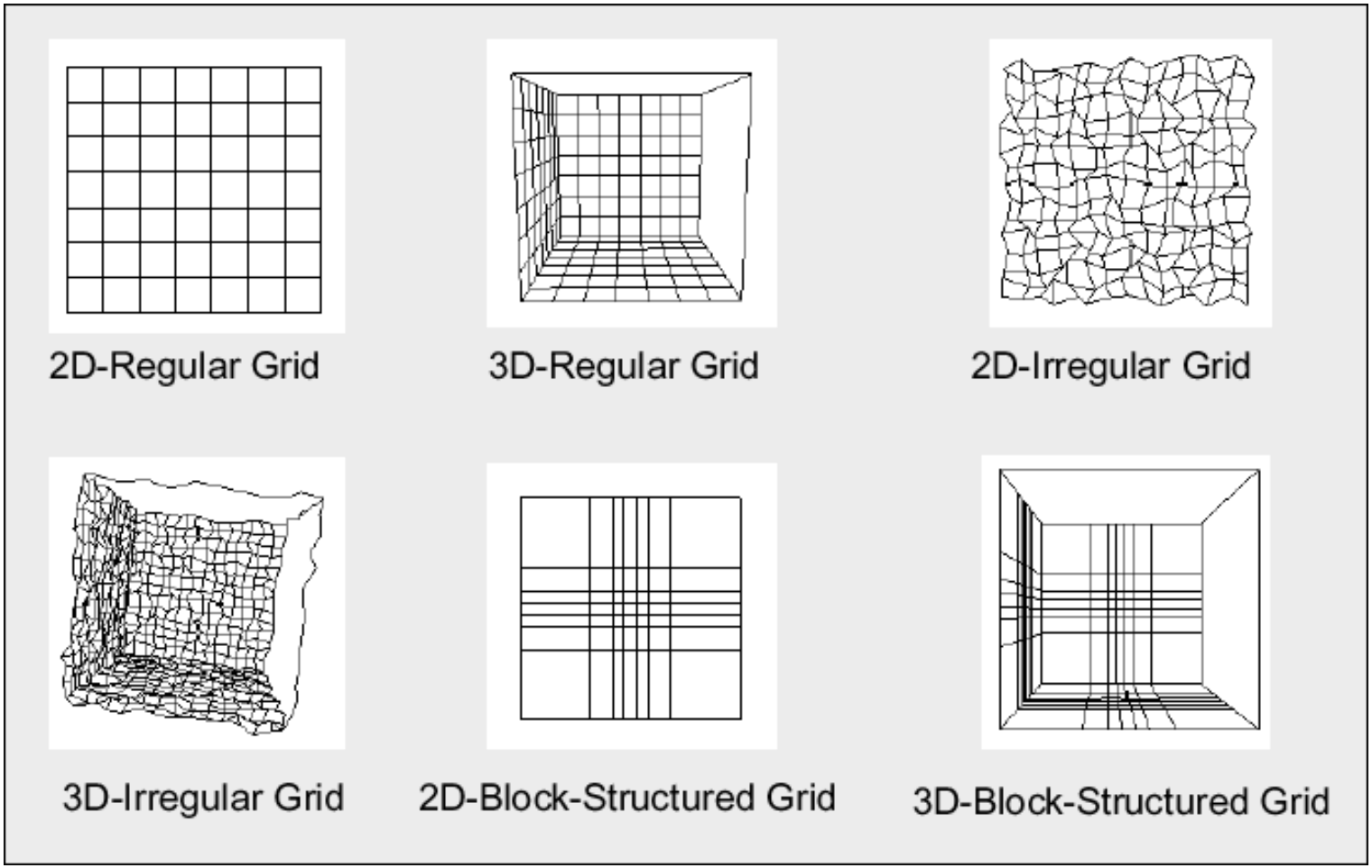


Grids

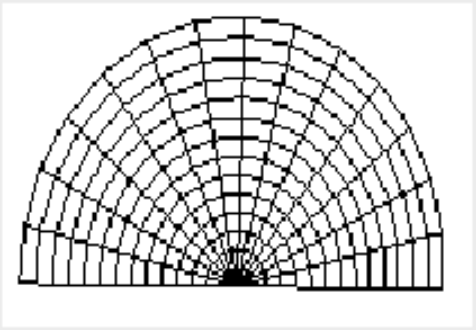
Data Structures

- domain structure
  - regular / grid
  - semi-regular (piecewise regular)
  - unstructured / scattered
- topology vs. geometry
  - linear, rectilinear, curvilinear
  - multigrids
  - sparse grids

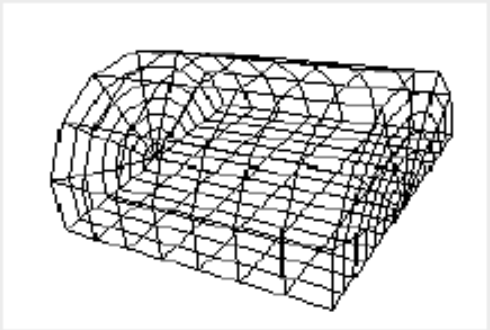
Data Structures



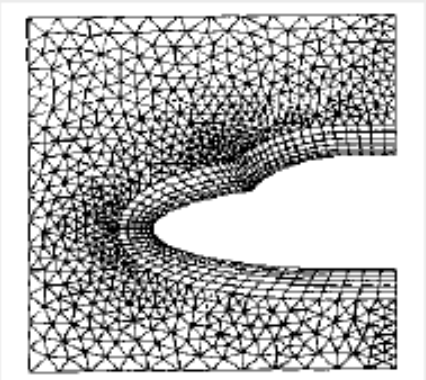
Data Structures



2D-Structured Grid



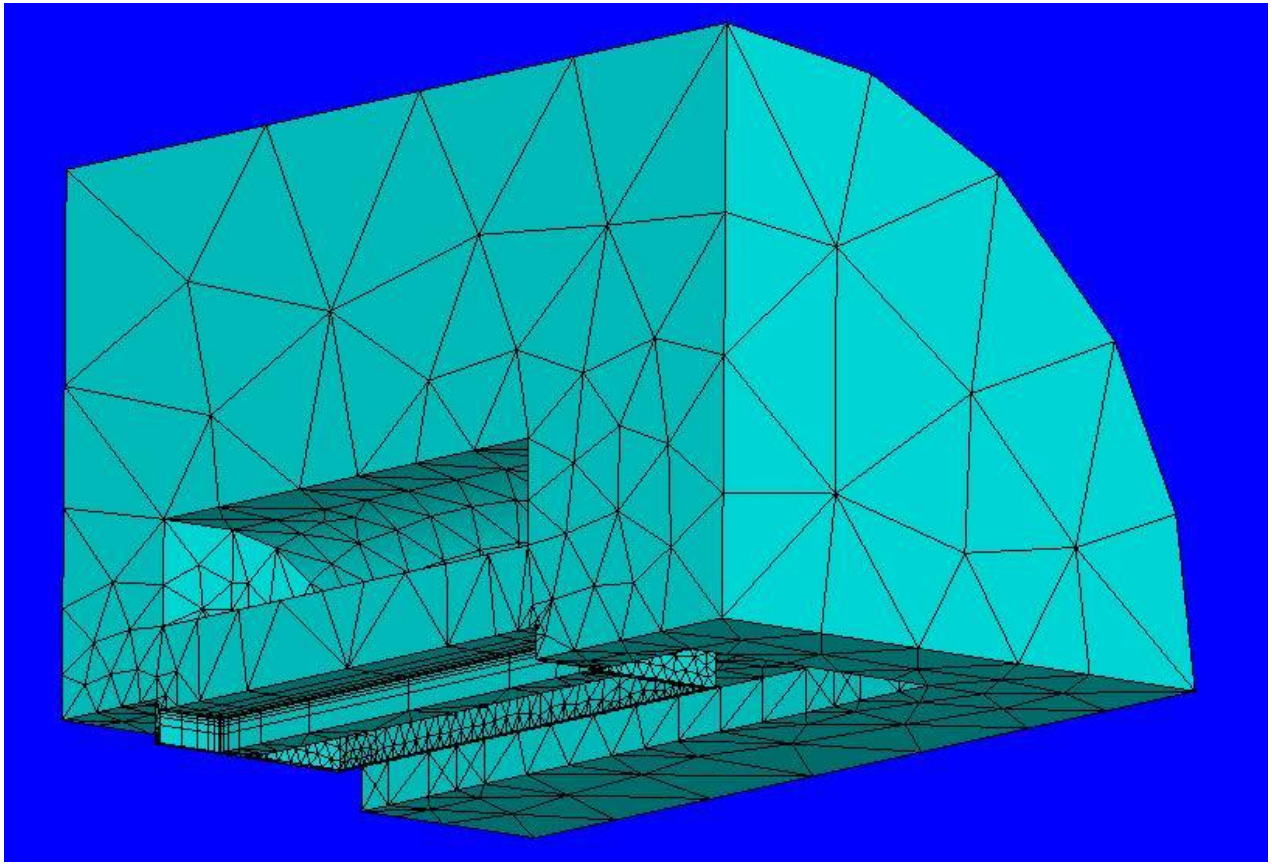
3D-Structured Grid



2D-Hybrid Grid

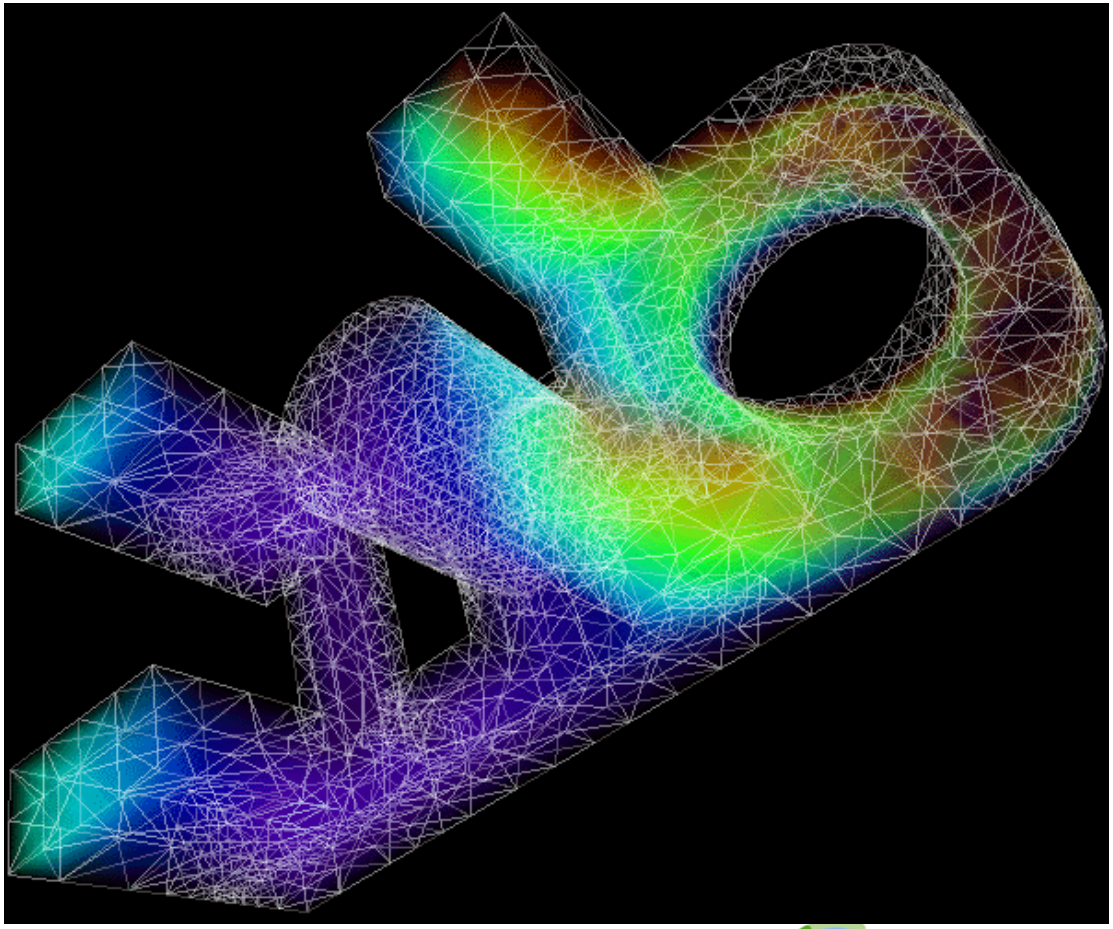
Data Structures

- Example



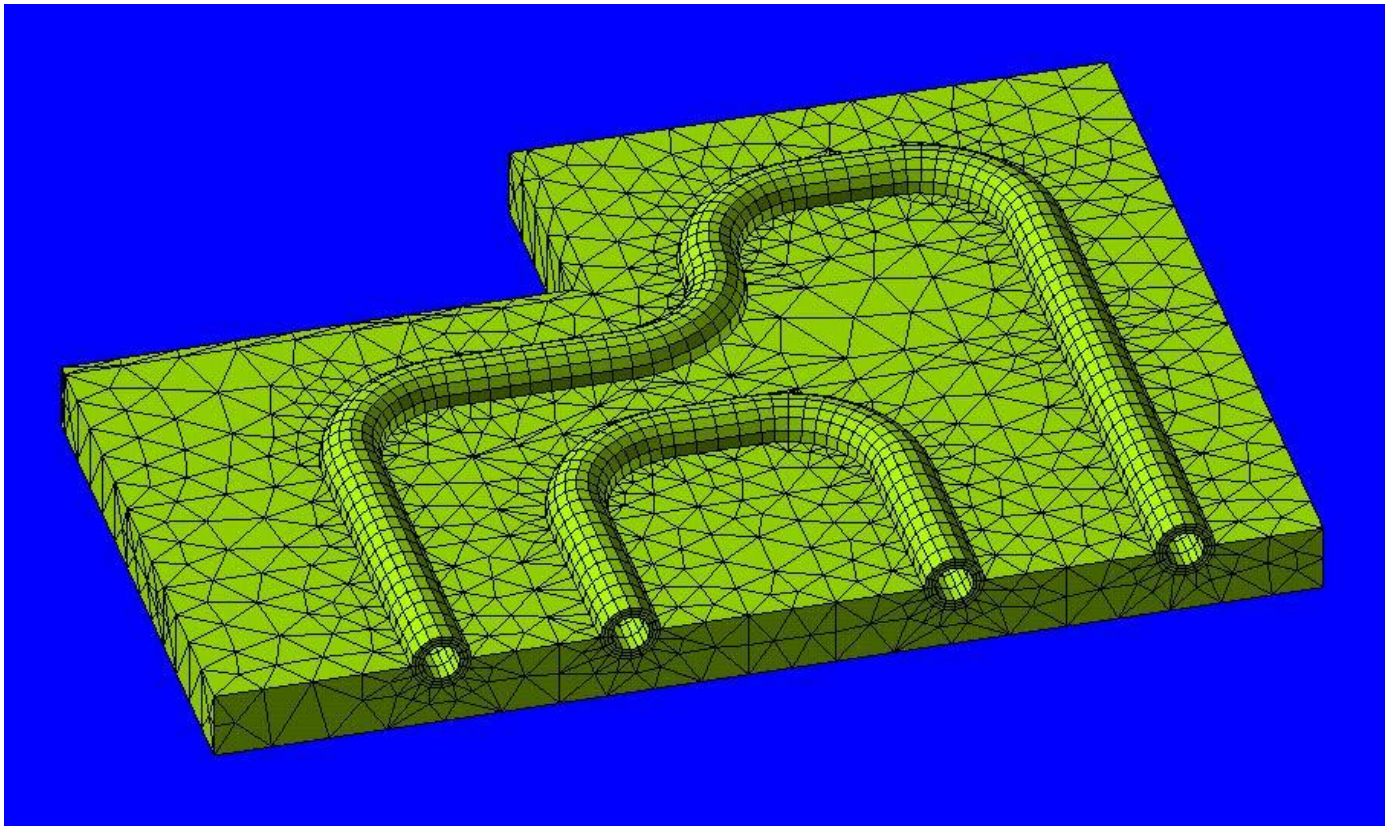
Data Structures

- Example



Data Structures

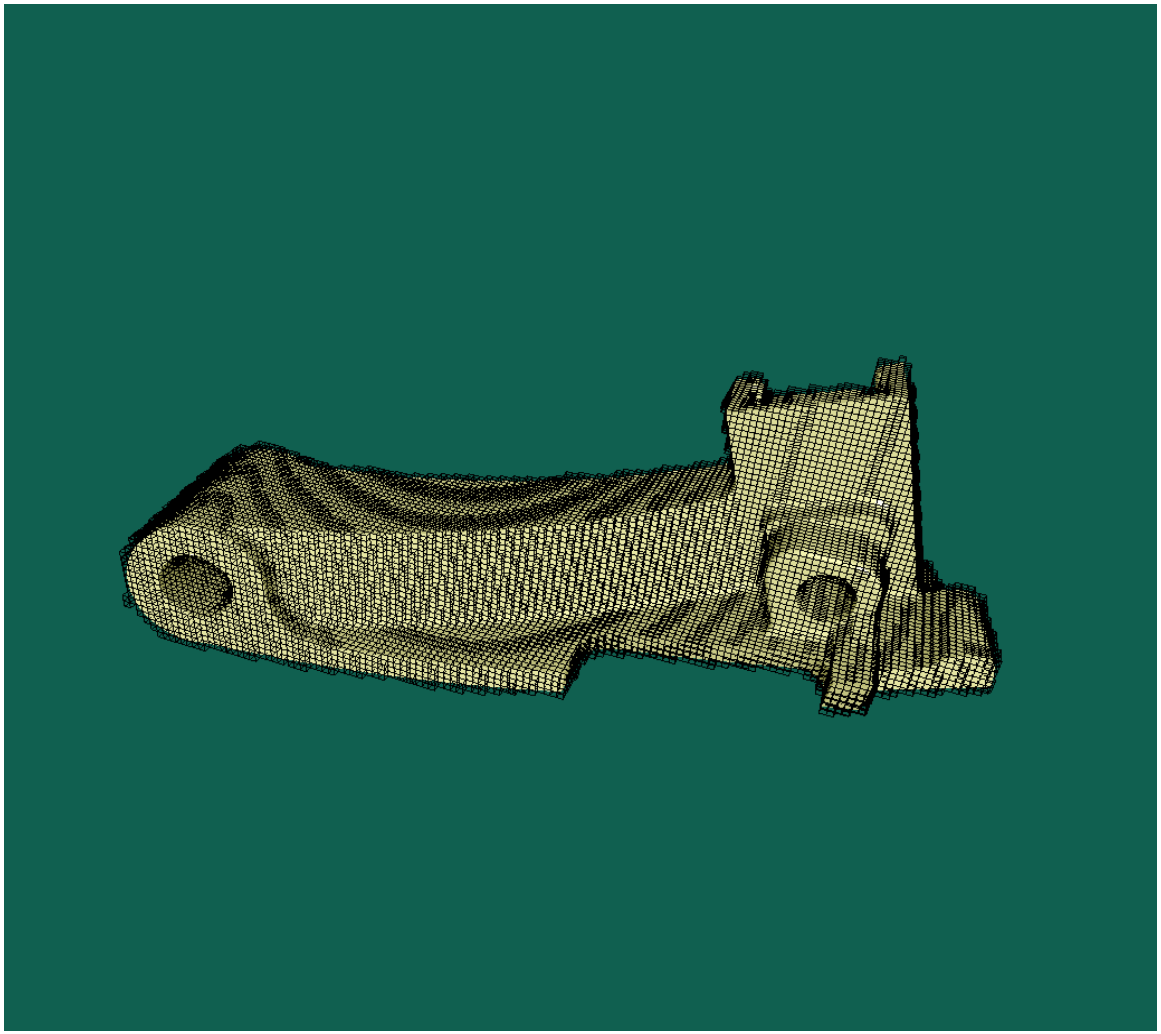
- Example



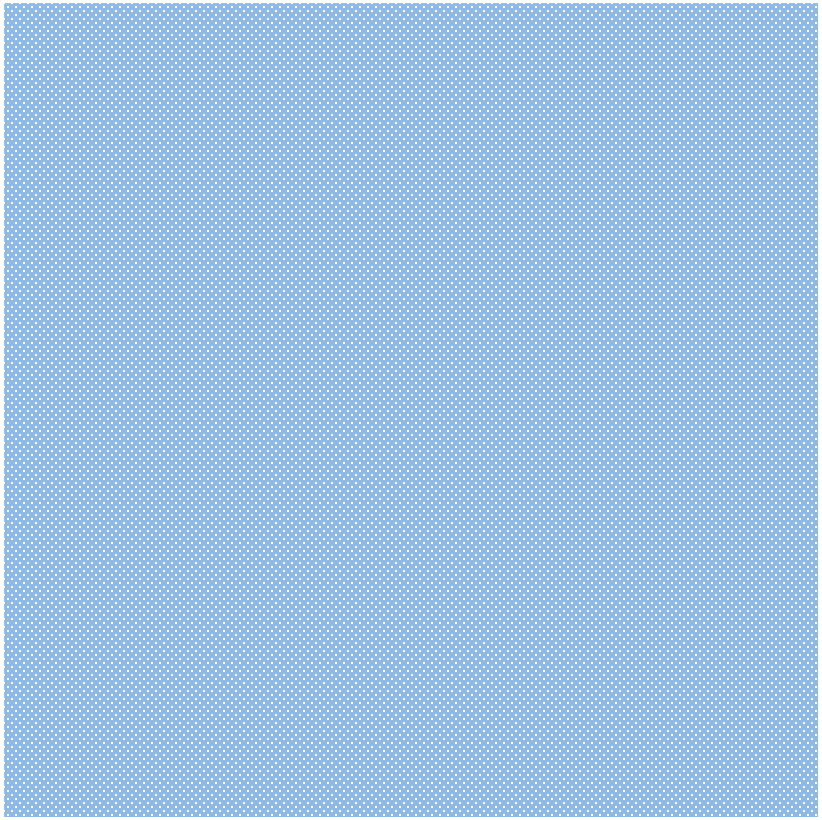
Volumetric Representations

- Voxel grid $\rightarrow O(h^{-3})$
- Adaptive octree
  - Three color octree $\rightarrow O(h^{-2})$
  - Adaptively sampled distance fields $\rightarrow O(h^{-1})$
- kD-Tree
- Binary space partition
  - Partition the space along arbitrary planes
  - Piecewise **linear** C^{-1} approximation
  - Align cells to surface

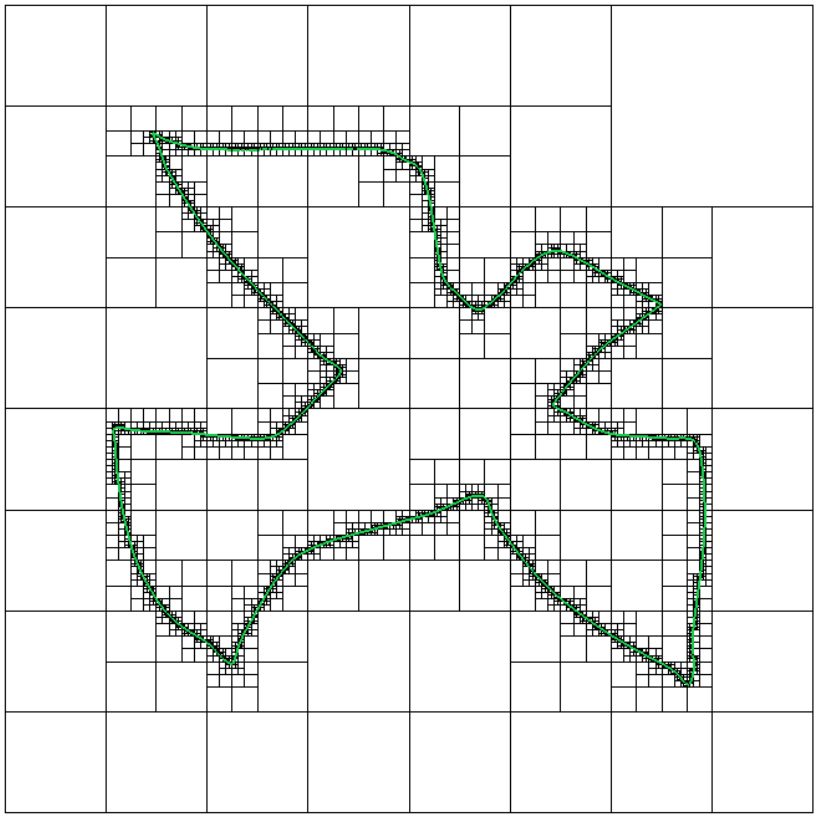
Three Color Octree



Three Color Quadtree

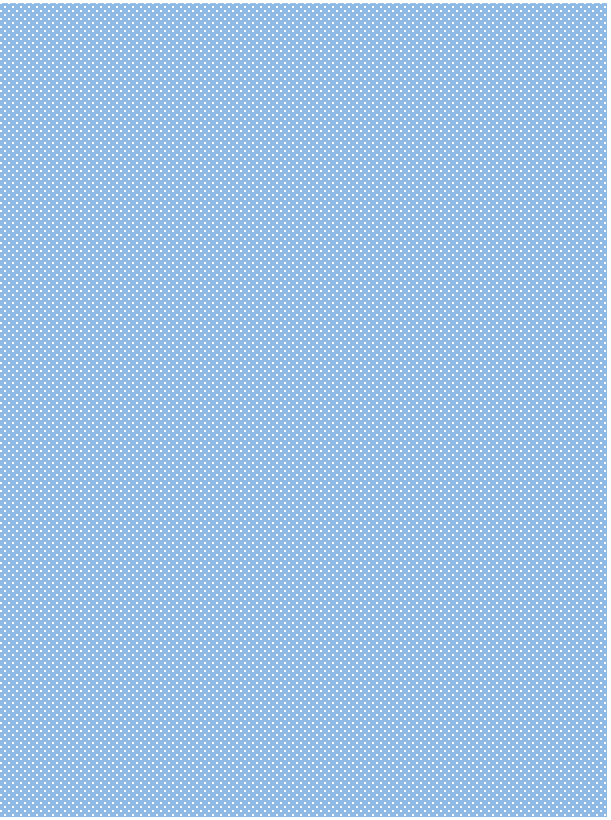


1048576 cells

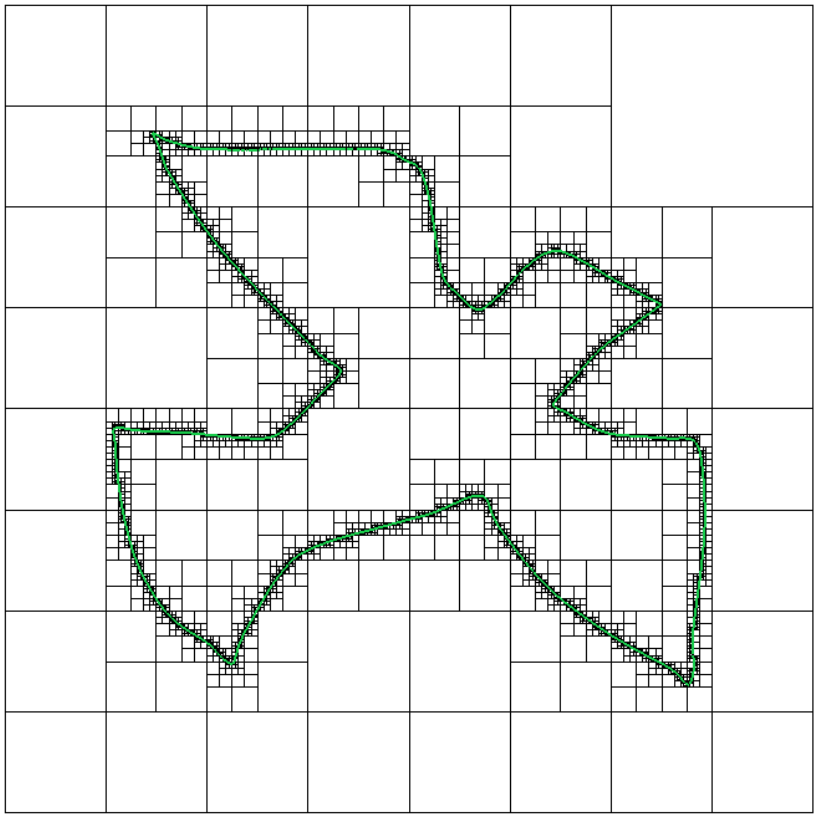


12040 cells

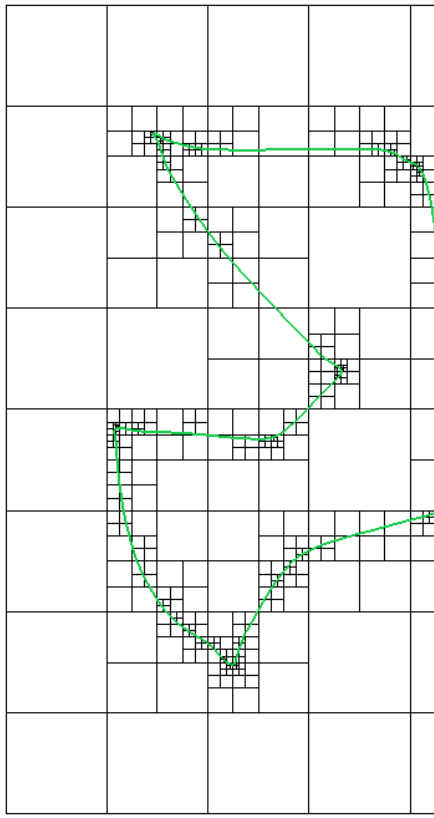
Three Color Quadtree



048576 cells

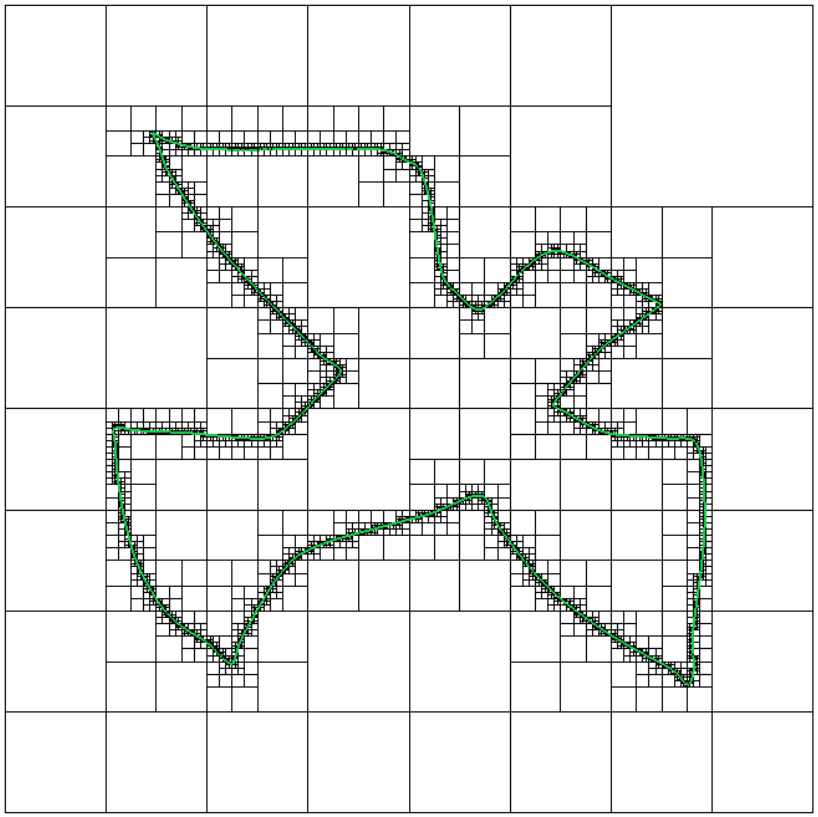


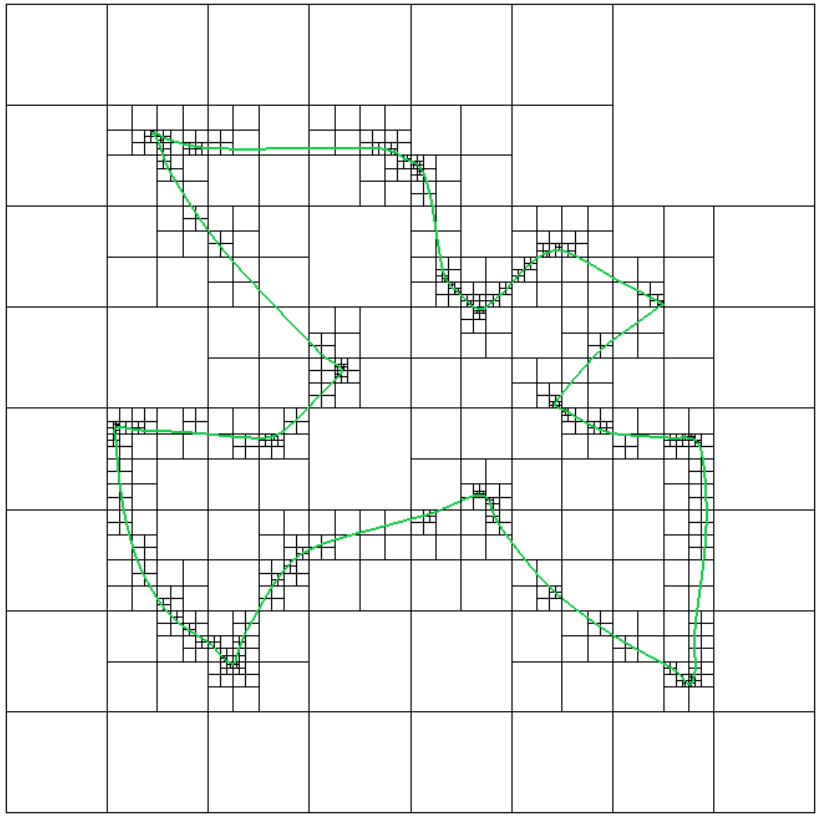
12040 cells



895 c

Adaptively Sampled Distance Fields



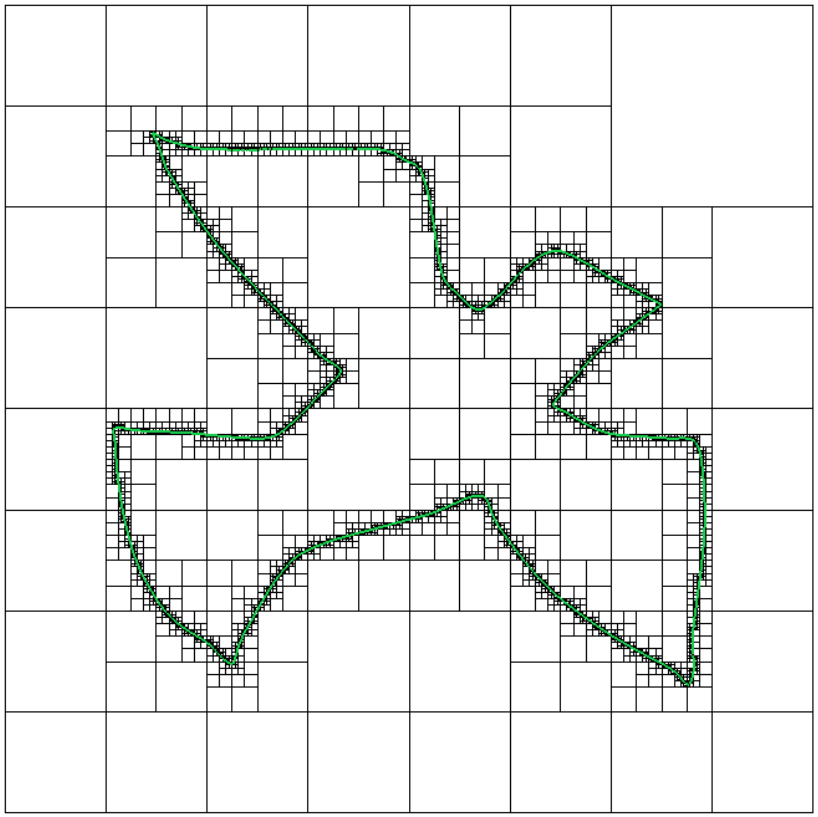


lls

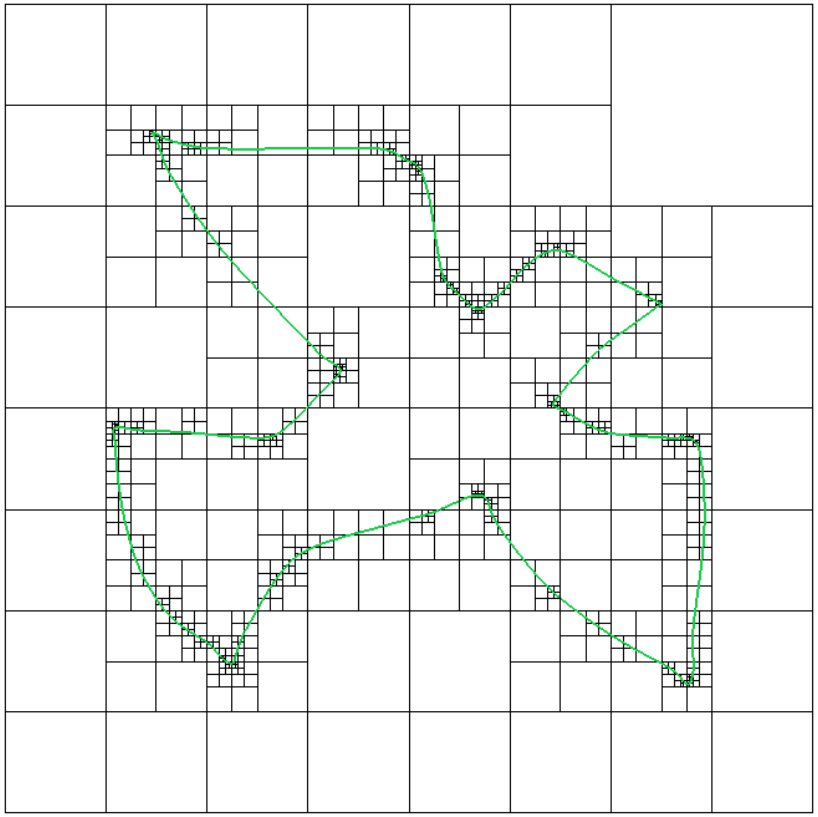
12040 cells

895 cells

Adapively Sampled Distance Fields

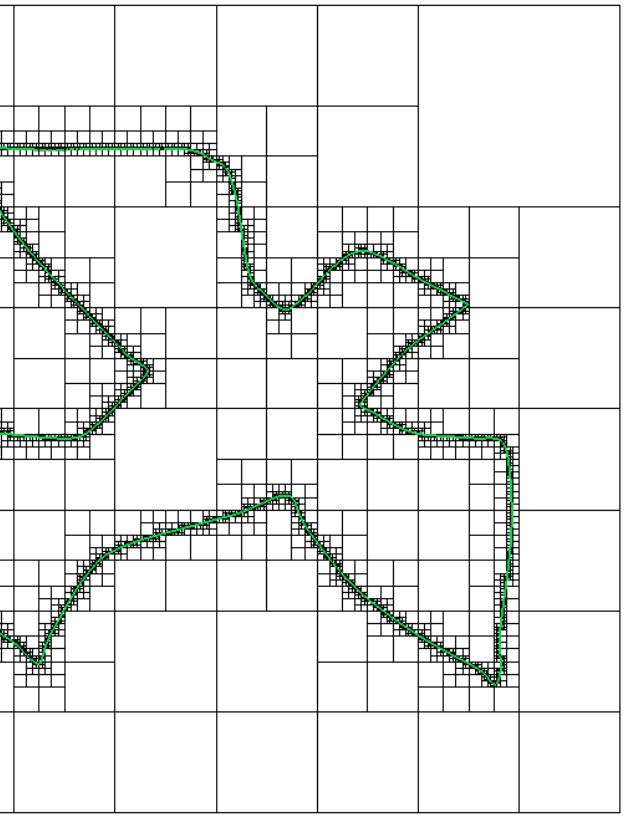


12040 cells

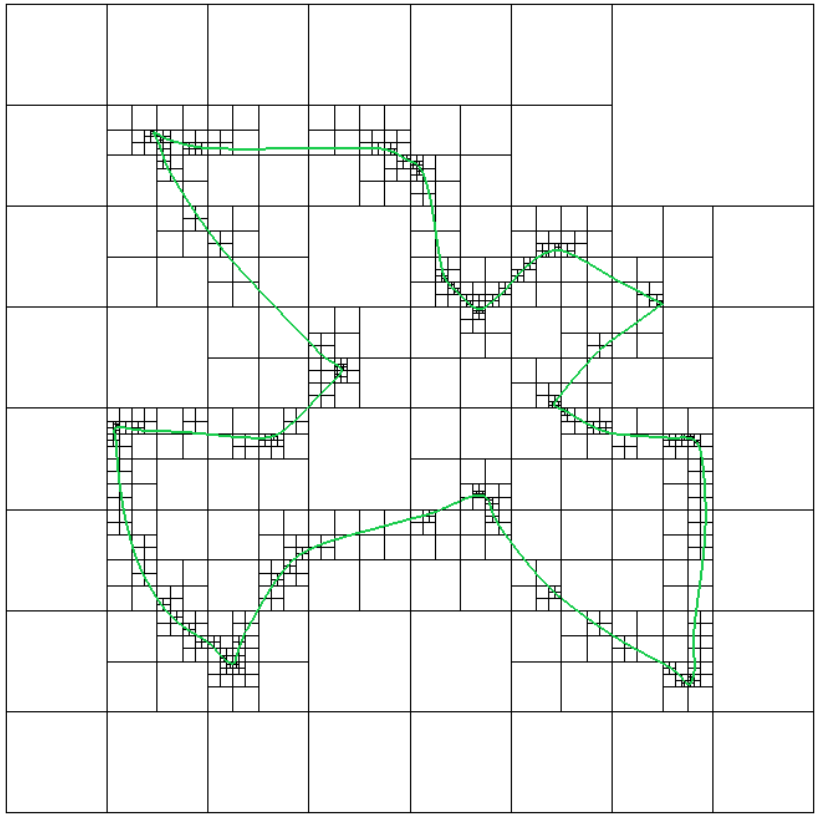


895 cells

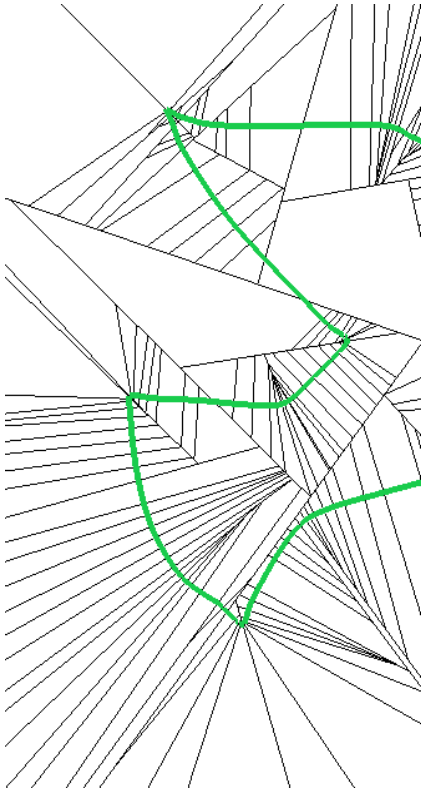
Adaptively Sampled Distance Fields



12040 cells

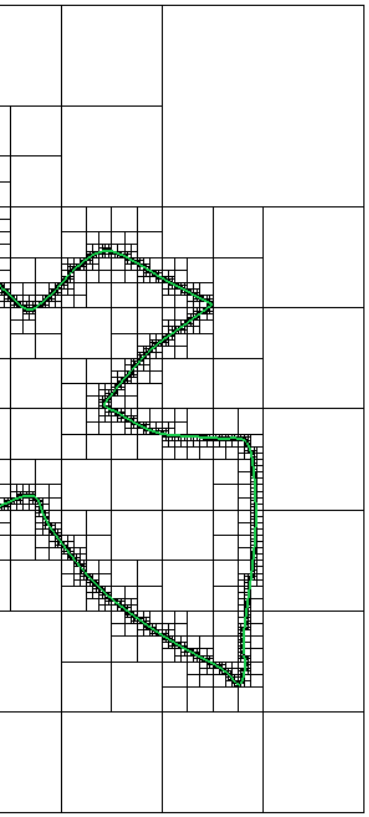


895 cells

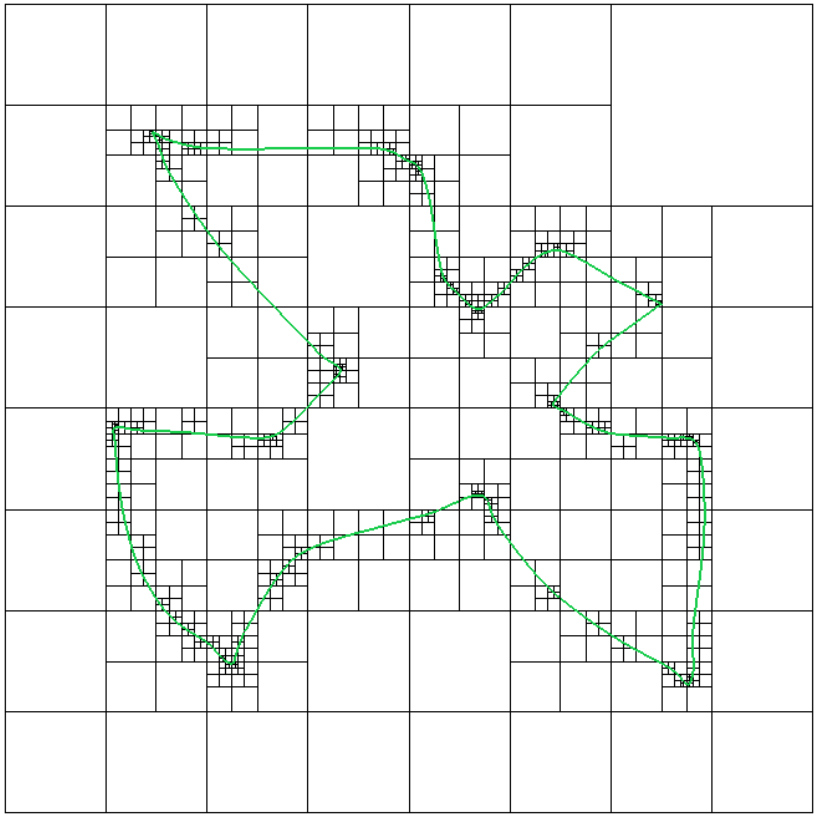


254

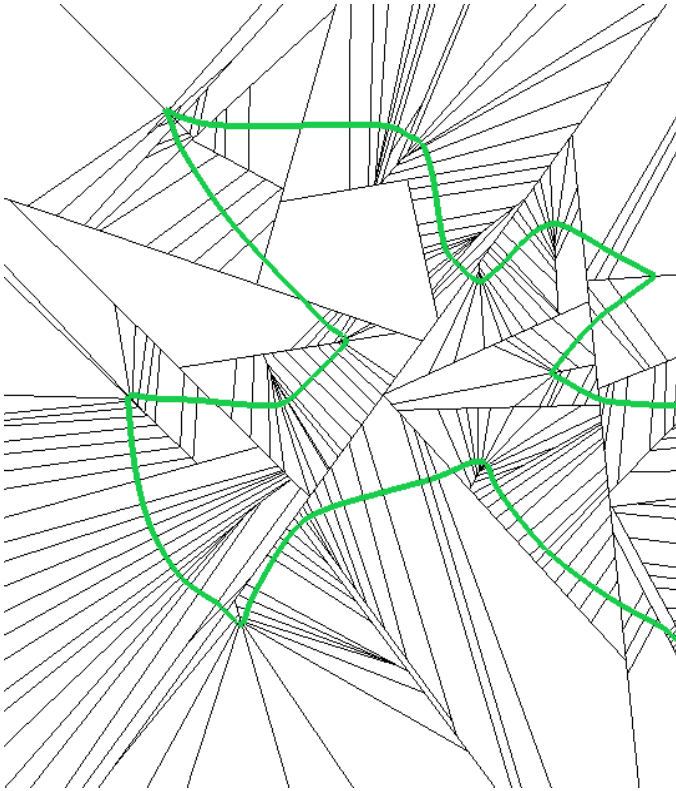
Binary Space Partitions



cells

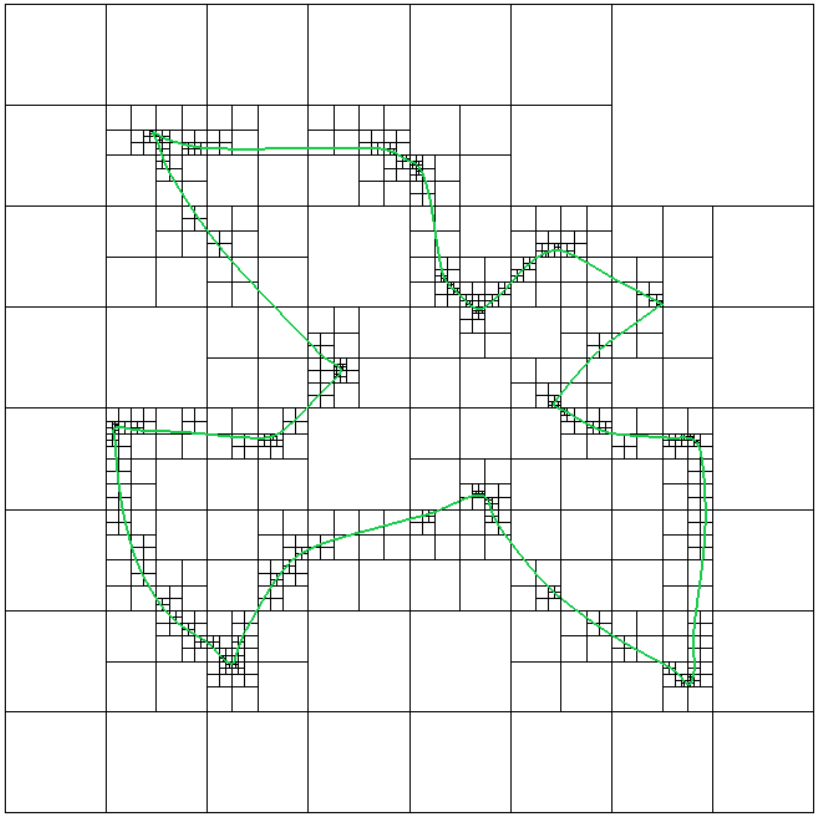


895 cells

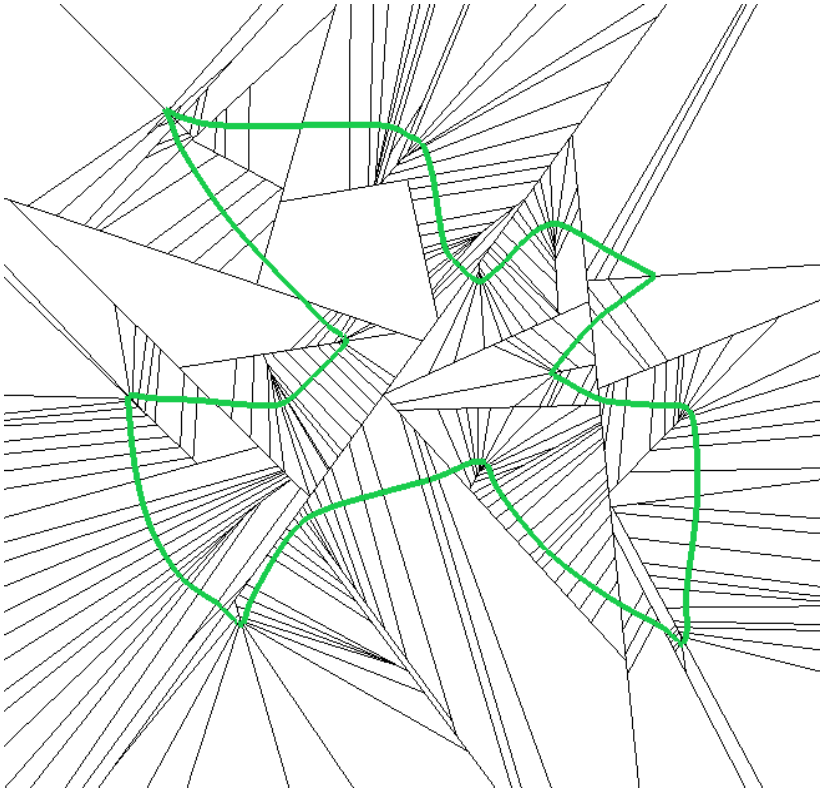


254 cells

Binary Space Partitions



895 cells

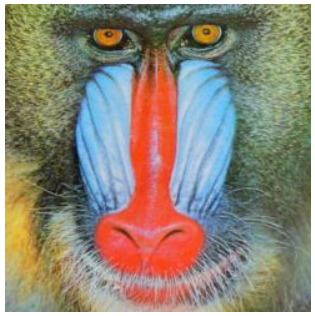


254 cells

Color Coding

Color Coding

- Issues:
  - What kind of data can be color-coded ?
  - What kind of information can be efficiently visualized?



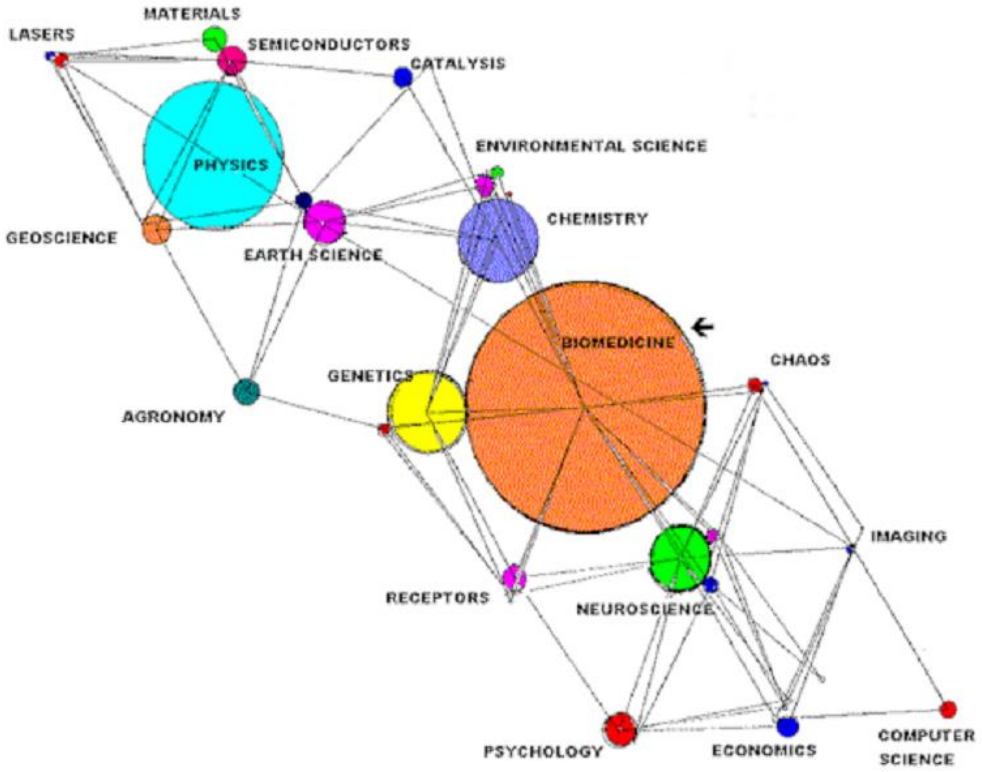
- Areas of application
  - Provide information coding
  - Designate or emphasize a specific target in a crowded display
  - Provide a sense of realism or virtual realism
  - Provide warning signals or signify low probability events
  - Group, categorize, and chunk information
  - Convey emotional content
  - Provide an aesthetically pleasing display

Color Coding

- Possible problems:
  - Distracts the user when inadequately used
  - Dependent on viewing and stimulus conditions
  - Ineffective for color deficient individuals
  - Results in information overload
  - Unintentional conflicts with cultural conventions
  - Cause unintended visual effects and discomfort

Color Coding

- Nominal data
  - Colors need to be distinguished
  - Localization of data
  - Around 8 different basis colors

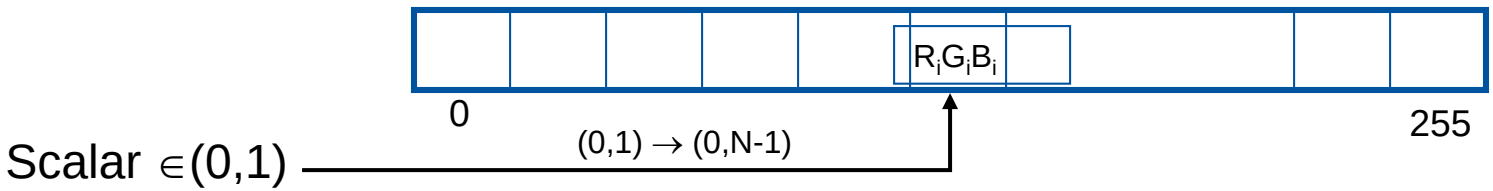


co-citation analysis

Color Coding

- Ordinal and quantitative data
  - Ordering of data should be represented by ordering of colors
  - Psychological aspects
  - $x_1 < x_2 < ... < x_n \rightarrow E(c_1) < E(c_2) < ... < E(c_n)$

- Color coding for scalar data
  - Assign to each scalar value a different color value
  - Assignment via transfer function *T*
    $T : scalarvalue \rightarrow colorvalue$
  - Code color values into a color lookup table



Color Coding

- Pre-shading vs. post-shading
  - Pre-shading
    - Assign color values to original function values (e.g. at vertices of a cell)
    - Interpolate between color values (within a cell)
  - Post-shading
    - Interpolate between scalar values (within a cell)
    - Assign color values to interpolated scalar values
- Linear transfer function for color coding
  - Specify color for f_{min} and for f_{max}
    - $(R_{min}, G_{min}, B_{min})$ and $(R_{max}, G_{max}, B_{max})$
  - Linearly interpolate between them

$$f \mapsto \frac{f - f_{min}}{f_{max} - f_{min}}(R_{min}, G_{min}, B_{min}) + \frac{f_{max} - f}{f_{max} - f_{min}}(R_{max}, G_{max}, B_{max})$$

Color Coding

- Different color spaces lead to different interpolation functions
- In order to visualize (enhance/suppress) specific details, non-linear color lookup tables are needed

- Gray scale color table
  - Intuitive ordering

- Rainbow color table
  - Less intuitive

- Temperature color table

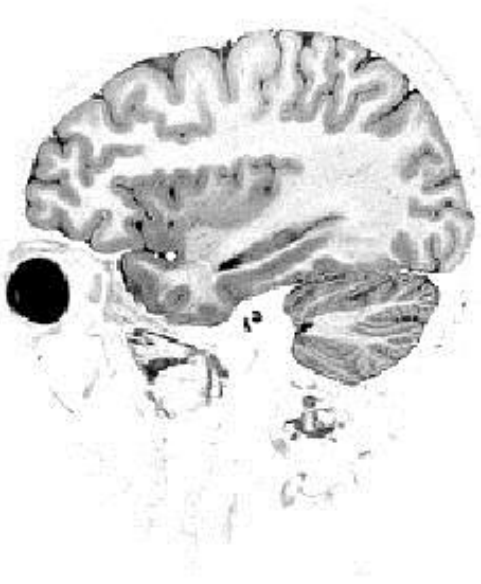
Color Coding

- Bivariate and trivariate color tables are not very useful:
  - No intuitive ordering
  - Colors hard to distinguish
- Many more color tables for specific applications
- Design of good color tables depends on psychological / perceptional issues
- Often interactive specification of transfer functions to extract important features

Color Coding

- Example
  - Special color table to visualize the brain tissue
  - Special color table to visualize the bone structure

Original



Brain

Tissue

Color Quantization

- Task:
  - Select a set of colors to represent the color gamut of an image
  - Compute mapping from color space to representrative color

- „True color“ image: 24 bits per pixel
- Colormap: 1 color index per pixel adresses color lookup table

Color Quantization

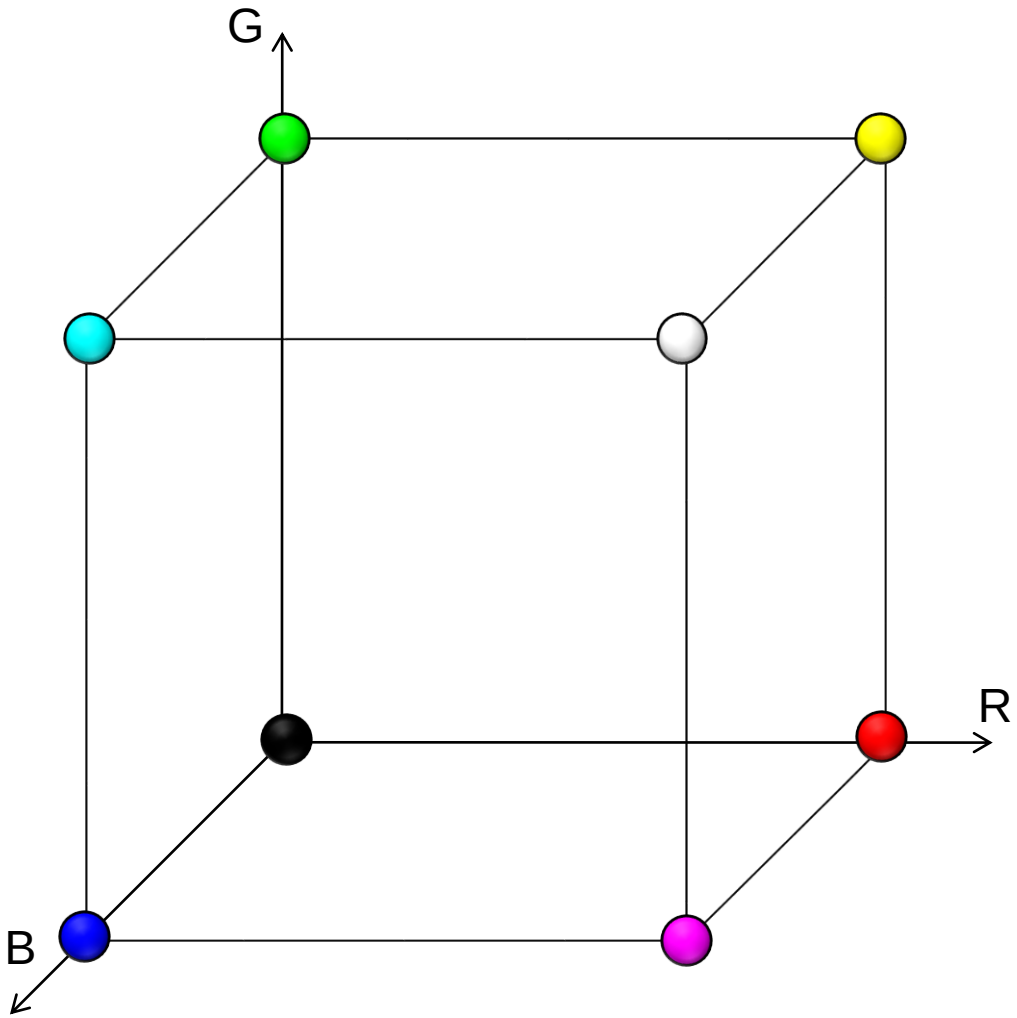
- Naive idea: Uniform quantization
  - Drawback: many colors in colormap are not used in final image

    ⇨ bad image reproduction

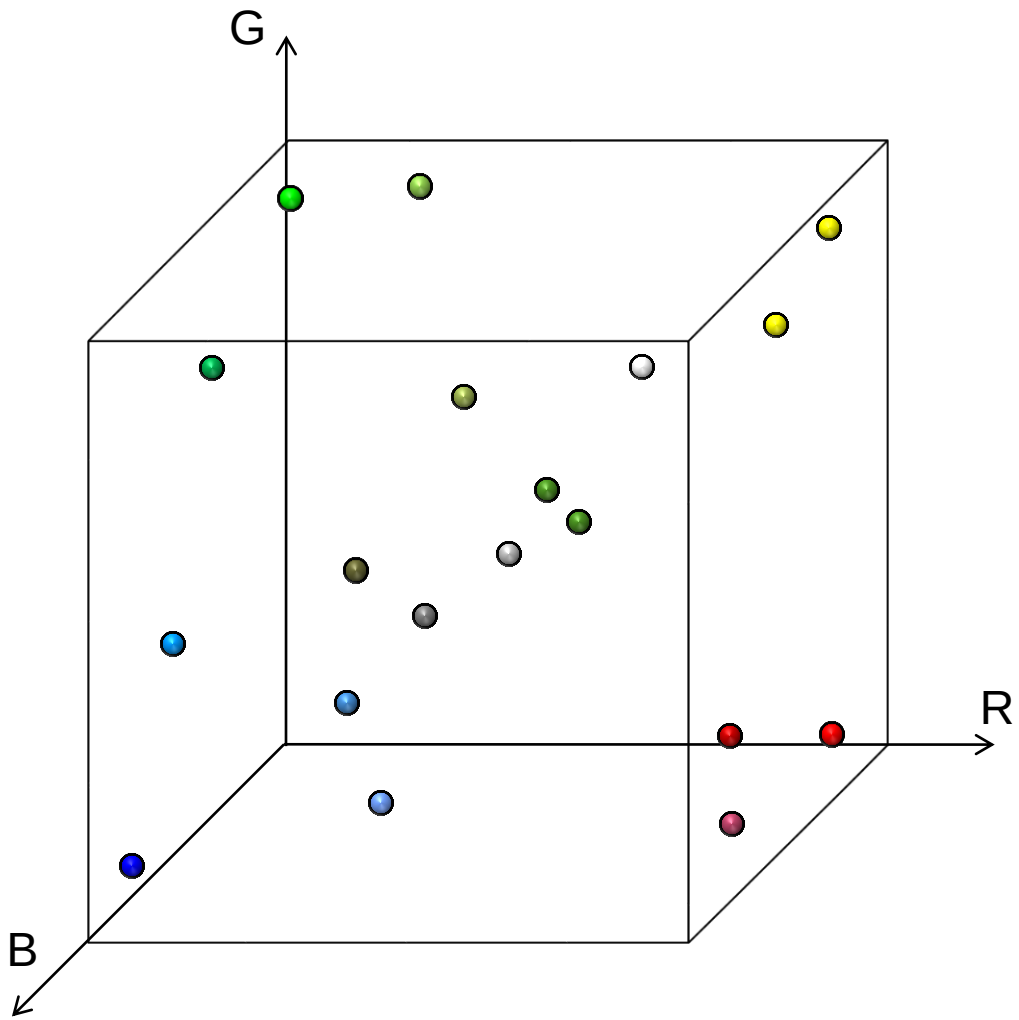
- Better: Median Cut Algorithm
  - Choose color map based on color distribution in original image
  - Pro: uses every color in the colormap

    ⇨ closer image reproduction

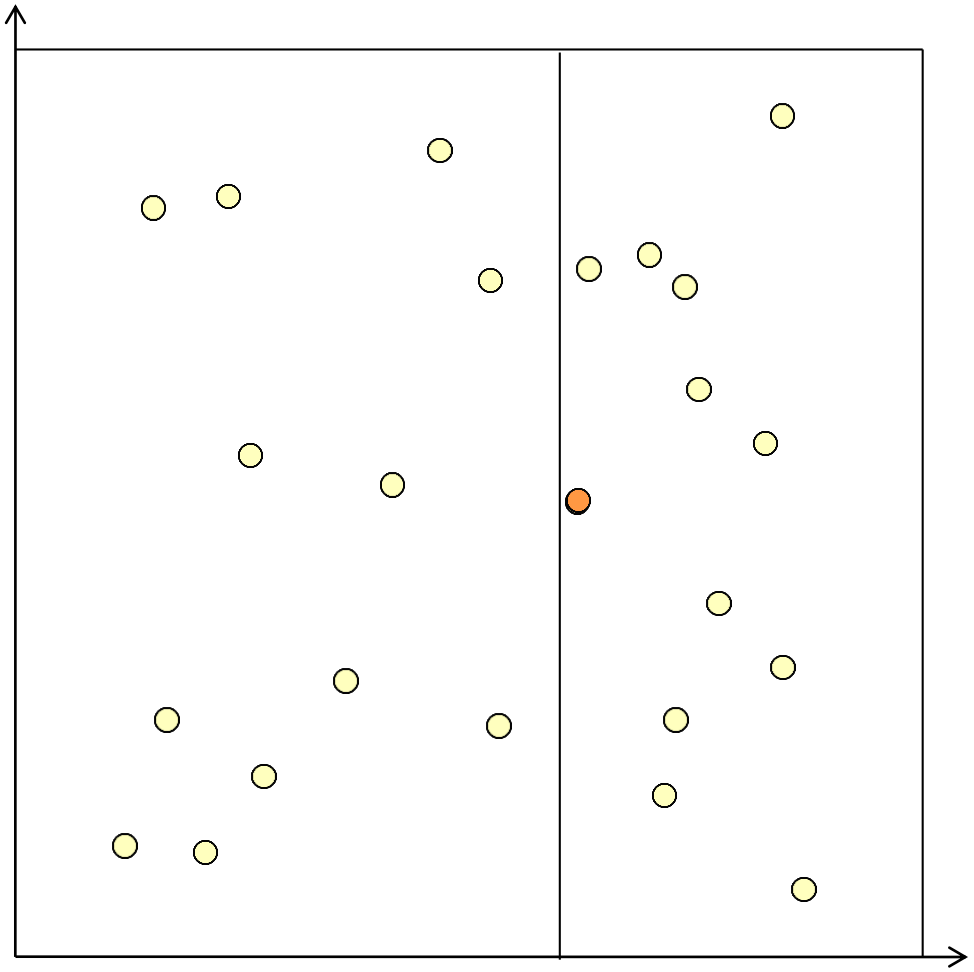
RGB Space



RGB Space

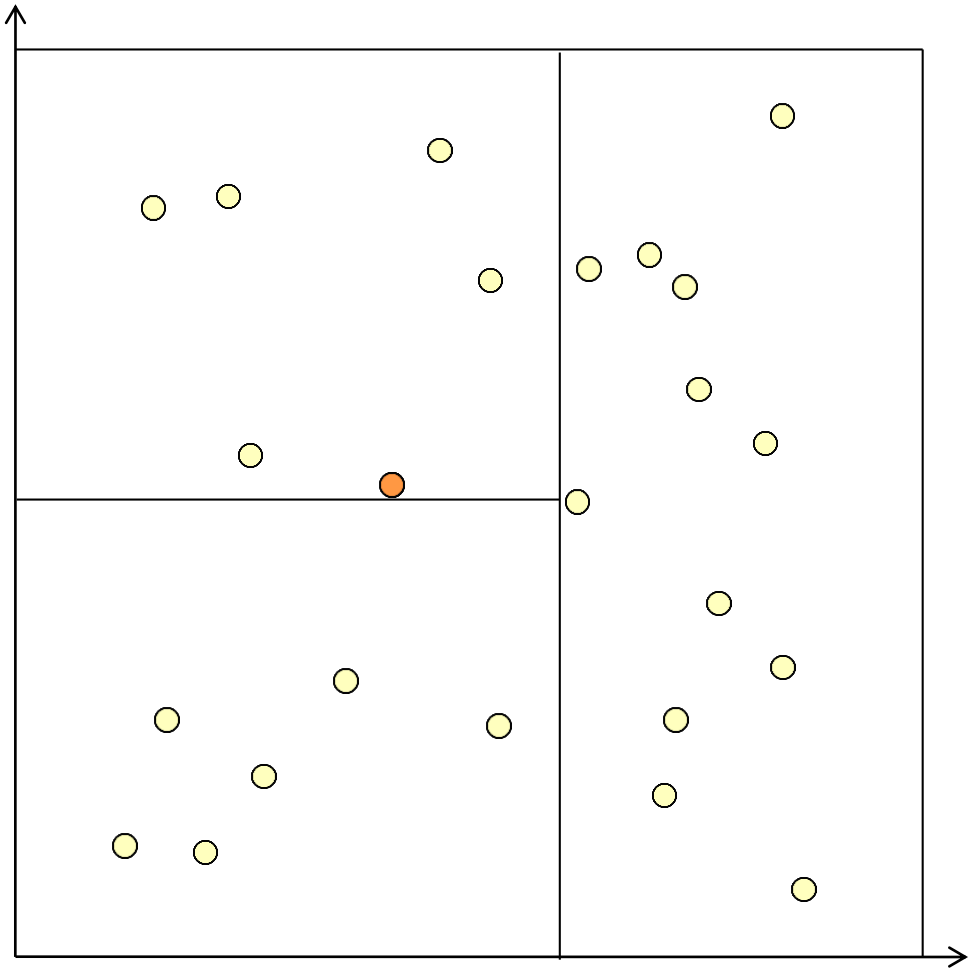


Median Cut (2D)



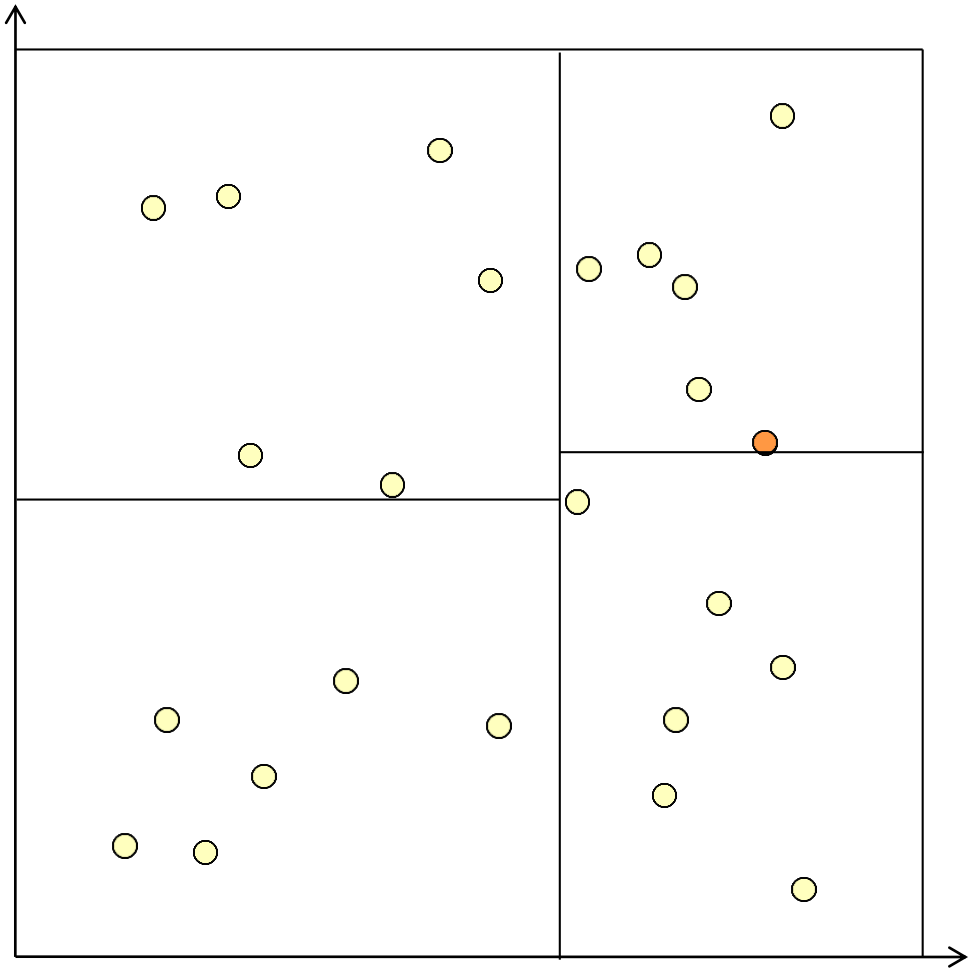
8 colors

Median Cut (2D)



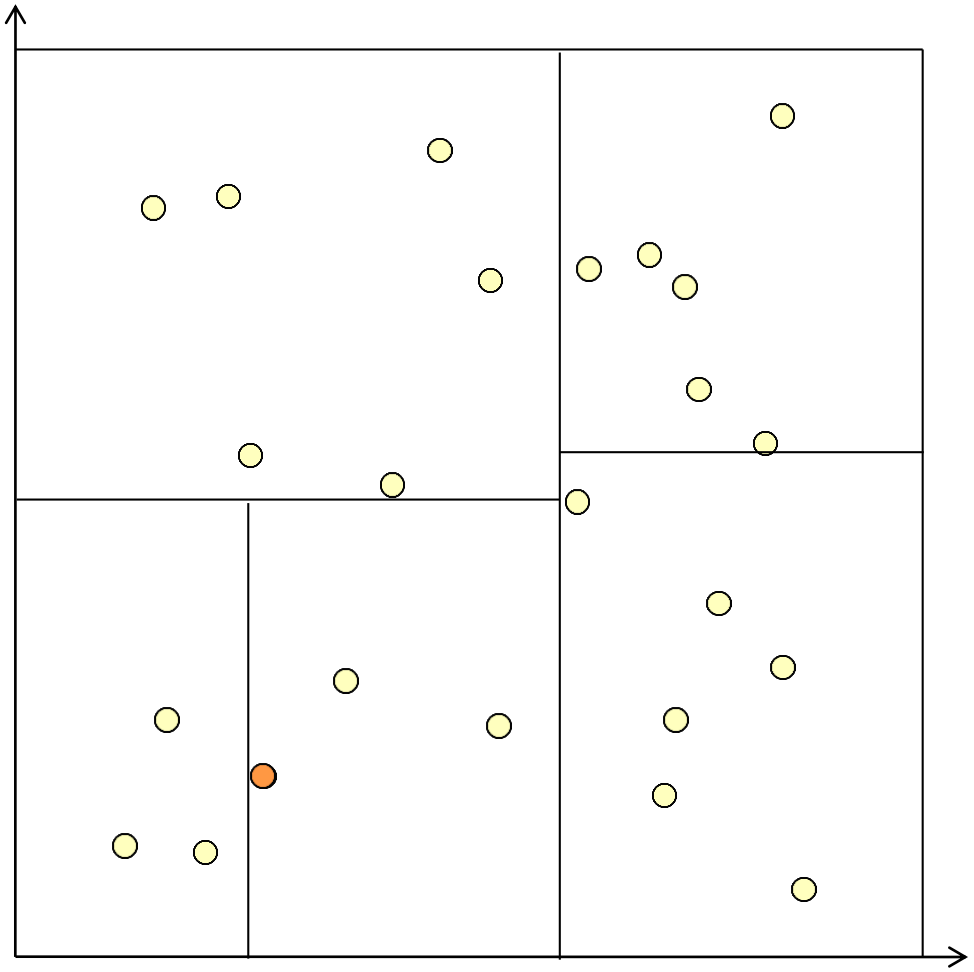
8 colors

Median Cut (2D)



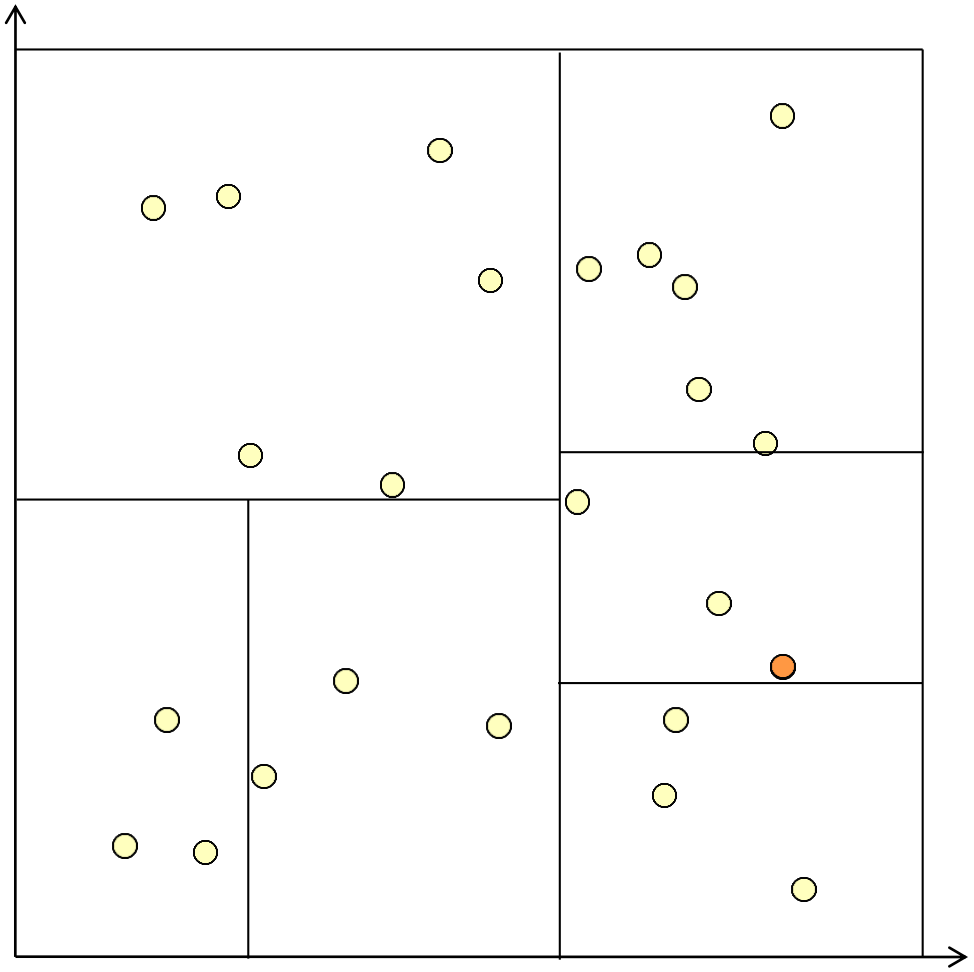
8 colors

Median Cut (2D)



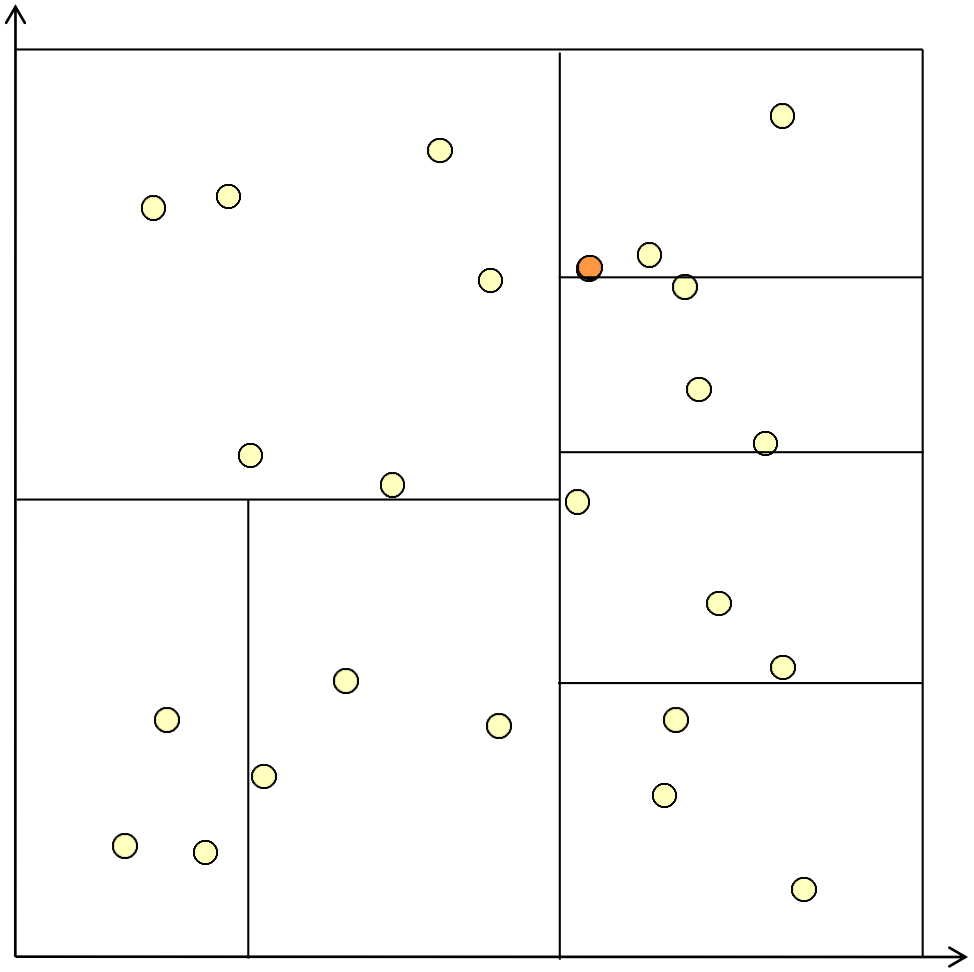
8 colors

Median Cut (2D)



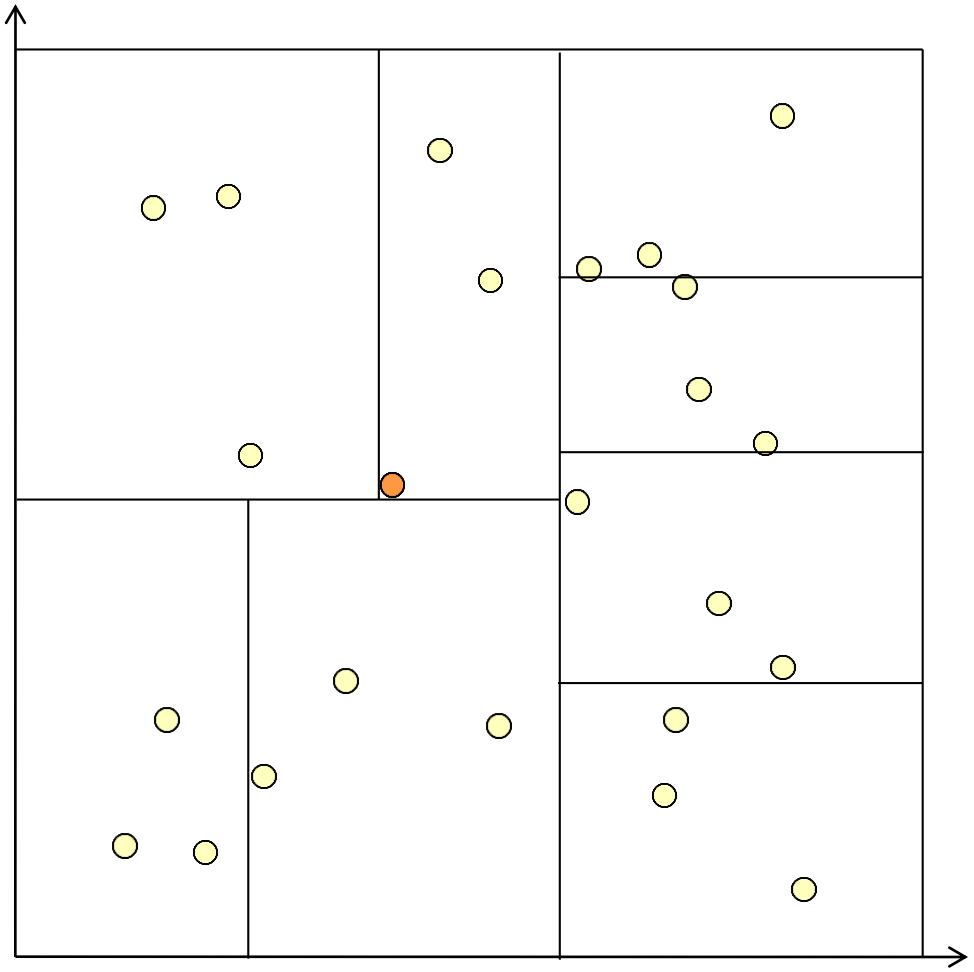
8 colors

Median Cut (2D)



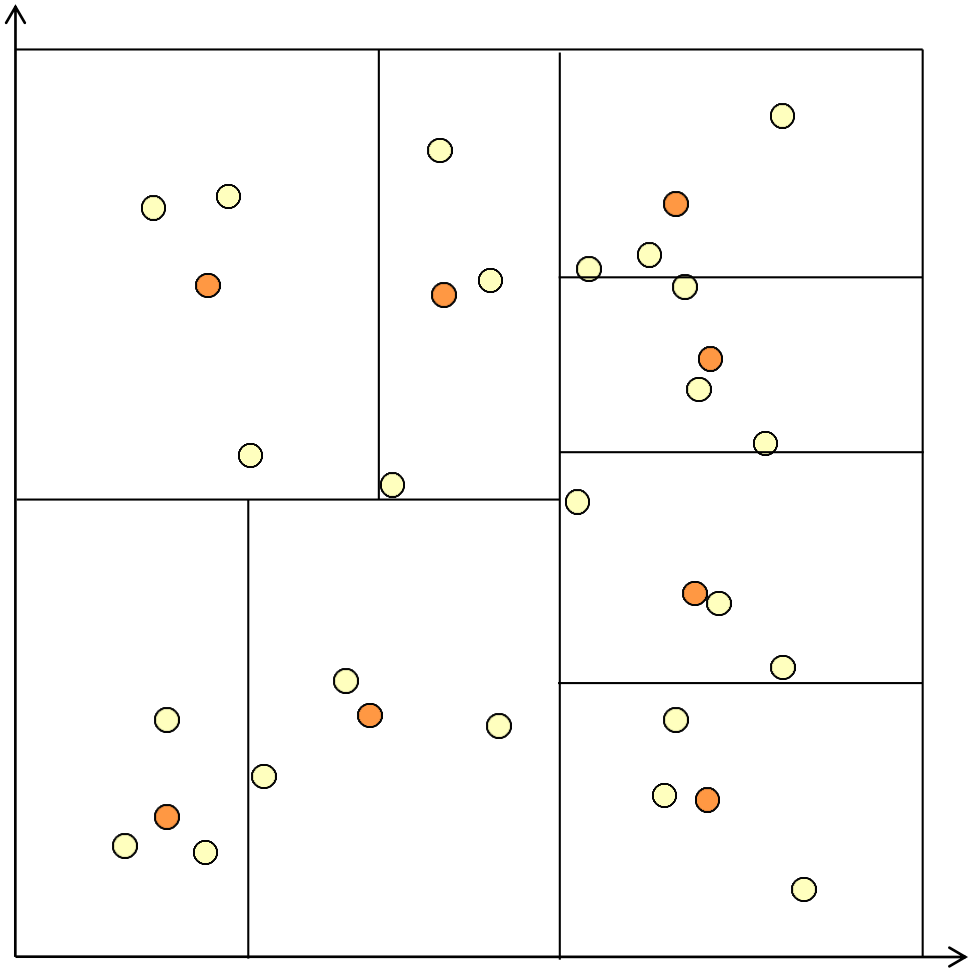
8 colors

Median Cut (2D)



8 colors

Median Cut (2D)



8 colors

Median Cut Algorithm

```
Color_Quantization(image I, k) {
  for each pixel in I
    map to RGB space
  B = {RGB space}
  for (i = 1 to k-1) {
    L = Heaviest(B)
    split L at median along longest dimension into L1 and L2
    remove L from B and add L1, L2
  }
  for each box in B
    assign color representative
  for each pixel in I
    map to representative
}
```

Color Quantization

16 Mio.

Color Quantization

256

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Data Analysis and Visualization

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Color Quantization

Color Quantization

64

Color Quantization

Color Quantization

Color Quantization

8

Color Quantization

16 Mio.